REPORT JTCG/AS-81-C-002

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THE AIRCRAFT INFRARED MEASUREMENTS GUIDE

Final Report

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March 1983

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Prepared for

THE JOINT LOGISTICS COMMANDERS
JOINT TECHNICAL COORDINATING GROUP
ON
AIRCRAFT SURVIVABILITY

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FOREWORD

The Aircraft Infrared Measurements Guide is the result of the work of numerous individuals--conferring, drafting, reviewing, and editing--all with the goal of providing guidance and, ultimately, some standardization. This guide is published with the intent that data requirers, data users, and data ensurers will read, critique, and use it. Comments concerning the guide's contents and experience in use of the guide are solicited. The Joint Infrared Standards Working Group intends to update and reissue the guide based on these comments. The Joint Technical Coordinating Group for Aircraft Survivability intends to standardize many aspects of measurements (data requirements, test plans, nomenclature, calibration, methodology, and data and report formats) based upon responses to the updated measurement guide. As a reader and user of this guide, your comments and suggestions could significantly impact the resultant measurements standards. Comments should not be limited to measurements in the infrared portion of the electromagnetic spectrum, but should include measurements across that portion of the spectrum using optical/electro-optical technology. Comments should be addressed to:

Commander/Director
Office of Missile Electronic Warfare
US Army Electronic Warfare Laboratory
ATTN: DELEW-M-TAS (T. Atherton)
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THOMAS A. ATHERTON
Chairman, Joint Infrared
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A reference source for the aircraft infrared measurement community is proposed. The guide provides standard nomenclature, suggested data formats, calibration requirements (including derived mathematics), and measurement methodology. Chapters are also included on developing test plans and writing the formal report. An extensive bibliography contains sections on calculations aids/equation, calibration, radiometry/spectrometry, and radiation sources.

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CHAPTER 1

INTRODUCTION

William L. Capps

PREFACE

The Aircraft Infrared Measurements Guide is one of several efforts of the Joint Infrared Standards Working Group to improve the quality, universality, and utility of measured aircraft infrared (ir) signature data. It was developed to set forth a reference of quality for the aircraft ir measurement community focusing on significant areas of aircraft ir signature measurements not treated adequately elsewhere.

BACKGROUND

The measurement of aircraft ir signatures started in earnest in the 1950's with the development and evolution of the SIDEWINDER "heat-seeking" missile. As passive infrared countermeasures (IRCM) and, later, active IRCM became accepted, they began to be the driving force for aircraft ir measurements. More recently, ir signature information has been required for application in detection and identification systems in satellites and for ship defense. During the period of growth of ir measurements, changes in the nature of defense research and development have had a significant impact on how measurements are made, the kinds of data available, and the inherent limitations on those measurements and data. In this time, detectors, measurement devices, and data requirements have changed and developed greatly.

The bulk of measurements made in the past have been designed to aid in specifying or evaluating particular aircraft system requirements or performance. Measurement efforts as a result have generally been narrowly scoped with little or no wide application for the measurement results. The conditions of measurements covered have been very limited with only samplings of what might be considered "typical" conditions. Few sets of measurement data could be compared directly without making a significant amount of "normalizing" or "adjusting" calculations based on broad assumptions. Data that were comparable were usually taken by the same organization and resulted from patterns of measurement technique more than any effort at repeatability. Data taken by different organizations most often required "normalization" or "adjustment" for comparison, and even then data comparison was still usually difficult.

As the ir signature user community grew, it became apparent that much or most of the available data were not readily applicable for other than the originally designed purpose. People entering the field, typically to find the signature of a particular aircraft, often found a confusing mixture of data from different sources.

The frustration of not being able to apply so much of the data that existed led to frequent cries of "this data is no good" and "most ir signature data is worthless."

In 1973, the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) under Capt. W. B. Rivers (USN) began to explore the complaint that too many measurements were made and too little data were useable. Capt. Rivers began with the assumption that the problem was a lack of standards. He visited many of the major aircraft ir measurement facilities and interviewed major measurement participants. A broad plan to address the problem was drafted. Funding was identified to establish a working group beginning in FY-76T.

The JTCG/AS subgroup on countermeasures (JTCG/AS-CM) was assigned the responsibility for setting up the working group and overseeing its activities. In August 1975, Mr. P. Sandler, chairman of the JTCG/AS-CM called the initial meeting of the working group at the Naval Air Systems Command in Washington, D.C. A number of broad objectives and possible activities were considered. Mr. William L. Capps of the Naval Weapons Center was tentatively appointed and later confirmed as chairman of the group and the title Joint Infrared Standards (JIRS) working group was selected.

JIRS was to be made up mainly of representatives from the most active ir measurement facilities within the Department of Defense (DOD) with some participation from DOD contractors. Specialists in areas such as field measurements, analysis, data reduction, and data applications were to be included.

The initial task set for the group was to assess the existing problems in aircraft ir signature measurements and to identify activities that would address the resolution or alleviation of the problems. There was early agreement that while standards needed to be addressed, a lack of what most people considered as basic "standards" was not a major problem. Basic measurement units were sometimes misused, and there were (and are) problems with nomenclature; however, while these problems may be irritating to a data user they could, most times, be resolved. The major problems seemed to lie more in variations to measurement approaches, different instruments, measurement philosophy, methods of reporting data, and the intended use of the data. Of the more than a dozen DOD laboratories and contractors making measurements, there was little commonality in measurement method or application, and little communication.

In addressing the various problems of the ir measurement community, JIRS decided asked these questions:

- how are measurements made at different facilities,

- what kinds of measurements are made,

- what are the perceived and actual measurement problems,

- what kinds of analyses of measurement results are required, and

- who are the users of measurement results and what are their general requirements?

The group started meeting on a quarterly basis rotating among measurement facilities. A survey of measurement instrumentation was made and a semiannual survey of aircraft ir measurement activity was started. In order to give meetings some central, individual structure, a list of major topics of interest was made. One of these topics was to be the focus of each meeting. As a number of meetings passed, the decision was made to continue to develop these topics as chapters in a guide for making aircraft ir signature measurements. This was done with each chapter being prepared by an individual JIRS member and subsequent critiquing by the entire JIRS membership. The result is the Aircraft Infrared Measurements Guide presented here.

MEASUREMENTS GUIDE

This guide should provide the basis for planning and conducting "good" measurements and obtaining results of excellence with wider applicability than previously realized.

It is organized into eight chapters covering an introduction, nomenclature, report format, data format, test plans, calibration, measurement methodology, and data applications.

Nomenclature

There is an abundance of literature on the nomenclature used in aircraft ir signature measurements. There is virtually no literature that brings the key nomenclature together in a single document. This chapter provides brief working definitions of the most often used terminology. The nomenclature is drawn from well established references in optical radiation, aircraft and engine characteristics, properties of materials, and the measurement and qualification of geometric quantities. Adequate references are provided. Growth in this chapter would be expected more in how these key symbols and terms are used than in the addition of more terms and symbols.

Report Format

The discussion of report format this early in the guide may seem premature. The point to be made is that the earliest consideration of the final report can be an important guiding factor in the development and conduction of tests, and certainly in the data reduction and analysis. The end product of an ir measurement program is virtually always a report. If there is a single common fault area in the loss and nonuseability of past aircraft ir measurement results, it is the absence of an adequate report. Without a good final report, essential details, decision considerations, limitations of the results, and rationals for conclusions are quickly lost.

Data Format

The data format chapter addresses the format in which data are to be presented in reports. The essential idea is that a commonality in data reporting format will allow for an easier, more consistent comparison of measurement results between different sources of information. Special attention is given to use of common geometric definitions and common graph scales.

Test Plans

The test plan is probably the least emphasized phase of an ir measurement effort with the exception of the final report. This essential guiding paper distills the homework that goes into the test program before any field work begins. The test plan is what keeps distractions and tangential factors from dominating the test and keeps the priority objective of the test in the forefront. This chapter can be considered the keystone of this guide. A well developed and proscecuted test plan will lead to most of the essential parts of the other chapters.

Calibrations

The calibrations chapter is probably one of the most needed chapters in the guide. A standard procedure for calibrating ir instruments is of utmost importance. Among other things, it provides a basis by which a comparison can be made between measurements of similar targets with different instruments. This chapter attempts to summarize the important aspects of the calibration of the ir radiometric instruments including radiometers, spectrometers, and spatial radiometers.

Measurement Methodology

Measurement methodology is frequently the key to how useful an aircraft ir signature measurement program becomes. There have been many significant measurement programs with well developed data collection efforts that have failed to have an impact or even to effectively see the light of day because

the methods and procedures of measurement and data reduction and analysis phases were underdeveloped and underfunded. Some experienced measurement managers have estimated that the data reduction, analysis, and final report should account for approximately half of the cost of testing. This is rarely the situation. The field test frequently absorbs eighty to ninety percent of the funding. It is the data reduction and analysis effort that translates the measurement results into meaningful data that can lead to the conclusions and answer the questions that the sponsor requires.

Data Applications

The chapter on data applications addresses the relation between the types of measurements that are made, the approach to the measurement, and the intended use of the resulting data. Of particular significance is the problem of data acquired for one application and the attempt to translate it for use in other applications. This chapter provides constraining guidelines and discusses the potential pitfalls of applying data results.

Several final points need to be made concerning achieving the goal of quality measurements and measurement results. Although this guide is designed to achieve that goal, it alone cannot guarantee quality. Better measurements and measurement results will cost more in better instruments, more mantime, and more expensive testing. Perhaps the most significant consideration though is the attitude of sponsors, activity managers, and measurement organizations. The material covered in this guide is fairly straightforward, but sometimes difficult; it is always taxing on patience, training, and careful planning. The people who sponsor, plan, execute, report, and apply the results of aircraft ir signature measurements will have to want better measurements and results, know what better data means, and be willing to pay the price.

CHAPTER 2

NOMENCLATURE

Dan Powlette

The purpose of this chapter is to provide working definitions for terminology often encountered in aircraft ir measurement/analysis reports. These definitions can be separated into five general areas:

1. optical radiation entities[1 2 3 4 5 6 7 8 9]

2. aircraft/engine parameters[10 11 12]

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[1]Wyatt, C. L., "Theory and Methods of Radiometric Calibration," Utah State University, 1977

[2]Spiro, I. J., "Radiometry and Photometry," Opt. Engr., Vol. 17, 1978

[3]International Lighting Vocabulary, 3rd Edition, Bureau Central de la CIE, 4 Av. de Recteur Poincare', 75-Paris 16^{e}, France Publication CIE No. 17 (E-1.1), 1970

[4]The International System of Units (SI), National Bureau of Standards Special Publication 330, 1977

[5]Nicodemus, F. E., Proposed Military Standard, Infrared Terms and Definitions, Part I, 1971

[6]American National Standard, Nomenclature and Definitions for Illuminating Engineering, (RP-16), Z7.1, 1967

[7]Jones, R. Clark, Terminology in Photometry and Radiometry, J. Opt. Soc. America, Vol. 53, 1963

[8]Self-Study Manual on Optical Radiation Measurements, Part 1, National Bureau of Standards Technical Note 910-2

[9]Zissis, G. J., Handbook of Military Infrared Technology, Chapter 1, Radiation Theory, Environmental Research Institute of Michigan, 1978

[10]Military Specification, MIL-E-8593A, October 1975

[11]Military Specification, MIL-E-5007D, October 1973

[12]Gas Turbine Engine Performance Station Identification and Nomenclature, Society of Automotive Engineers, Inc., ARP 755A, 15 April 1974

3. properties of materials[5 6 9 13]

4. measurement geometry quantities, and

5. instrument-related characteristics.[1 5 9]

The importance of standardization of optical radiation terminology cannot be overemphasized. Three new optical radiation terms have been proposed:[1 2]

1. Pointance--from a point

2. Areance--from or upon an area

3. Sterance--related to a steradian

These new names provide three distinct advantages over the old terms:

- they satisfy the need of relating the names to the physical and geometrical concepts;

- they provide a common set of terminology whether the basic flux-related entity deals with watts, lumens, or quanta and,

- they provide useful terms for basic optical radiation entities where no terms previously existed.*

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*For example, there was no term for the specific entity with the units of quanta per second and meter squared (q $s^{-1}m^{2}$).

[1]Wyatt, C. L., "Theory and Methods of Radiometric Calibration," Utah State University, 1977

[2]Spiro, I. J., "Radiometry and Photometry," Opt. Engr., Vol 17, 1978

[5]Nicodemus, F. E., Proposed Military Standard, Infrared Terms and Definitions, Part I, 1971

[6]American National Standard, Nomenclature and Definitions for Illuminating Engineering, (RP-16), Z7.1, 1967

[9]Zissis, G. J., Handbook of Military Infrared Technology, Chapter 1, Radiation Theory, Environmental Research Institute of Michigan, 1978

[13]Geometrical Considerations and Nomenclature for Reflectance, National Bureau of Standards Monograph 160, 1977

The proposed basic optical radiation entities are listed in table 2-1 along with their recommended symbols and units. The bracketed terms are those adopted by the International Commission on Illumination[3] (CIE). (The CIE standard is the most commonly used and accepted terminology.) When it is not clear from the context, the subscripts e, v, and p can be used to denote flux as energy rate (watts), visible (lumens), and photon flux (quanta/second), respectively; and the optical terms can be prefixed with the respective modifiers--radiant, luminous, and photon.

It is recommended that these basic optical radiation entities be used in measurement/analysis reports. Th first time they are used they should be followed by the old terminology ith units in parenthesis; e.g., radiant sterance (radiance, watt $m^{-2}sr^{-1}$). Term definitions are listed in table 2-2.

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[3]International Lighting Vocabulary, 3rd Edition, Bureau Central de la CIE, 4 Av. de Recteur Poincare', 75-Paris 16^{e}, France Publication CIE No. 17 (E-1.1), 1970

TABLE 2-1. BASIC OPTICAL RADIATION ENTITIES

Terms	Symbols	Units
Flux	Φ	Φ
Radiant Flux (watts)	Φ_e	W
Luminous Flux (lumens)	Φ_v	lm
Photon Flux (quanta per sec)	Φ_p	q/s
Pointance [intensity]	I	Φ/sr
Radiant Pointance [radiant intensity]	I_e	W/sr
Luminous Pointance [luminous intensity]	I_v	lm/sr
Photon Pointance [- - - -]	I_p	$qs^{-1}sr^{-1}$
Exitent Areance [exitance]	M	Φ/m^2
Exitent Radiant Areance [radiant exitance]	M_e	W/m^2
Exitent Luminous Areance [luminous exitance]	M_v	lm/m^2
Exitent Photon Areance [- - - -]	M_p	$qs^{-1}m^{-2}$
Incident Areance [- - - -]	E	Φ/m^2
Incident Radiant Areance [irradiance]	E_e	W/m^2
Incident Luminous Areance [illuminance]	E_v	lm/m^2
Incident Photon Areance [- - - -]	E_p	$qs^{-1}m^{-2}$
Sterance [- - - -]	L	$\Phi\ m^{-2}sr^{-1}$
Radiant Sterance [radiance]	L_e	$W\ m^{-2}sr^{-1}$
Luminous Sterance [luminance]	L_v	$lm\ m^{-2}sr^{-1}$
Photon Sterance [- - - -]	L_p	$qs^{-1}m^{-2}sr^{-1}$

TABLE 2-2. DEFINITIONS

Energy (Q)	Work, heat, or any physical quantity that can be transformed into heat.
Flux (ϕ)	The time rate of flow of energy.
Pointance or Intensity (I)	The flux radiated by a source per unit solid angle in a particular direction.
Exitent Areance or Exitance (M)	The flux radiated from a source into a hemisphere per unit area of the source.
Incident Areance (E)	The flux radiated upon a surface per unit area of the surface
Sterance (L)	The flux radiated by a source per unit solid angle in a particular direction and unit projected area of the source perpendicular to that direction.
Contrast Pointance or Contrast Intensity (ΔI)	The target (absolute) pointance minus the product of the solid angle subtended by the target and the sterance of the background. Note: this assumes that the background is an isotropic radiator.
Solid Angle of a Cone (ω)	The area intercepted on the surface of a unit-radius sphere by the cone with its vertex at the center of the sphere.
Steradian (Ω)	The solid angle which, having its vertex at the center of a unit-radius sphere, subtends a unit area of the spherical surface.
Spectral	Differential entities with respect to wavelength (or frequency); functional properties with respect to wavelength (or frequency).
Apparent	Uncorrected for measurement path atmospheric attenuation.
Effective	Referenced to a specific radiometer/seeker normalized system response.

TABLE 2. SHEET 2

Maximum Thrust (MAX) or Afterburner Thrust (A/B)	The highest thrust for a limited time.
Intermediate Thrust (INT) or Military Rated Thrust (MRT)	The highest non-augmented thrust for a limited time (not less than 30 minutes).
Maximum Continuous Thrust (MAX CONT) or Normal Rated Thrust (NRT)	The highest thrust without constraint.
EGT (T5)	Exit gas temperature;[a] a temperature in the tailpipe section aft of the last turbine stage and before the augmentor on afterburning turbofan/turbojet engines (EGT is not affected by A/B operation).
TIT (T4)	Turbine inlet temperature* or combustor discharge temperature; usually a temperature between the combustor and turbine stages.
PTIT (T4.5)	Power turbine inlet temperature; a temperature between the gas generator turbine and the power turbine on turboshaft engines.
Turbine RPM	Percent of the maximum turbine turn rate as defined by the engine manufacturer (also referred to as engine RPM).
Rotor Torque	Percent of maximum torque as defined by helicopter manufacturer.
IAS	Indicated air speed; the reading of the air speed indicator as installed in the aircraft without correction for air speed indicator system errors but including the sea level standard adiabatic compressible flow correction.

[a]EGT and TIT are sometimes not measured directly but are computed from temperature data obtained from one or more locations within the engine. T5 refers to the temperature at station 5.

TABLE 2. SHEET 3

CAS	Calibrated air speed; indicated air speed corrected for position and instrument errors.
EAS	Equivalent air speed; calibrated air speed corrected for adiabatic compressible flow for the given altitude.
TAS	True air speed; equivalent air speed corrected for air density for the given altitude.
Absorptance (α)	The ratio of the power absorbed by a surface to the total incident power.
Transmittance (τ)	The ratio of the power transmitted through a surface to the total incident power.
Reflectance (ρ)	The ratio of the power reflected off a surface to the total incident power. (Note: $\alpha + \tau + \rho = 1$)
Emissivity (ε)	The ratio of the power radiated by the surface of a body to that of an ideal blackbody ($\varepsilon = 1$) radiator at the same temperature.
Slant Range (R)	The distance between the target aircraft and the sensor at the time of the measurement.
Elevation (el)	Angle above (positive) or below (negative) the principal horizontal plane of the aircraft.
Azimuth (az)	Angle in the zero elevation plane measured clockwise (looking down) from the longitudinal axis of the aircraft.
Altitude (Z)	Height above mean sea level of the sensor or target during the measurement.
True (or magnetic) Heading (H)	Direction (measured clockwise) from true (or magnetic) north.

TABLE 2. SHEET 4

Responsitivity	Output per unit input of effective incident areance, e.g., volts watt^{-1} meter squared
NEI	Noise equivalent irradiance (formerly NEFD noise equivalent flux density), an effective incident areance that produces a coherent signal output equal to the incoherent noise output (watts per meter squared)
FOV	Field of view; the angular measure of the volume of space within which an optical system can respond to the presence of a target. A system designed to search for a target usually has a small **instantaneous** field of view that is moved systematically to cover a much larger **total** field of view.
Resolution	The smallest interval separating two inputs for which they can be distinguished as two separate inputs - wavelength (frequency) intervals correspond to **spectral** resolution, angular intervals correspond to **spatial** resolution, and time intervals correspond to **temporal** resolution.
Throughput	The product of the area of a beam of radiation (normal to its direction of propagation) and the solid angle that the beam includes. Also called geometrical extent or étendue.

CHAPTER 3

REPORT FORMAT

Stanley E. Tate

PURPOSE

This technical data report format is intended to be a standard guide for activities involved with the reporting of infrared (ir) measurement tests. Every effort has been made to keep this standard guide consistent with the format requirements established in MIL-STD-847A, "Format Requirements for Scientific and Technical Reports Prepared by or for the Department of Defense" of 31 January 1973 as amended 21 June 1974.

BACKGROUND

A reconsideration of data reports was requested to improve the effectiveness of both data acquisition and dissemination of information. This need arose from certain difficulties encountered applying the existing ir data base to a wide variety of current requirements in design, field application, and new data generation planning. Reports describing analyses and experiments have a special mission to fulfill. These two activities involve the calculation or measurement of special characteristics of a specific test item. The calculated or measured results are the only product returned to the sponsor for his use in accomplishing his mission.

DETAILED FORMAT REQUIREMENTS

Order of Elements

Although all reports do not necessarily contain all the following elements, those that are used will appear in the following order with the abstract appearing only on the Report Documentation Page, DD Form 1473:

FRONT MATTER

- Front Cover (required)
- Report Documentation Page, DD Form 1473 (required)
- Summary
- Preface
- Table of Contents
- List of Illustrations

- List of Tables

BODY OF REPORT

- Introduction
- Conclusions
- Recommendations
- Main Text

REFERENCE MATERIAL

- References
- Bibliography
- Appendices
- Glossary of Terms
- List of Abbreviations, Acronyms, and Symbols
- Index
- Distribution List
- Back Cover (required)

Front Matter

Outside Front Cover. Include on the cover the information shown in the following paragraphs plus special markings, such as security classification and schedule for downgrading and declassification. Group related items as shown in figure 3-1.

Group I.

- Report number. The unique alphanumeric designation, or report number will be placed in the upper portion of the cover. See paragraph 5.2.1.1 of MIL-STD-847A for procedures for establishing a report number.

Group II.

- Title and subtitle. Display the title prominently and make it indicate clearly and briefly the subject of the report. Set subtitle, if used, in smaller type or otherwise subordinate it to the main title. When a report is prepared in more than one volume, repeat the primary title and have the subtitles identify specific volumes.

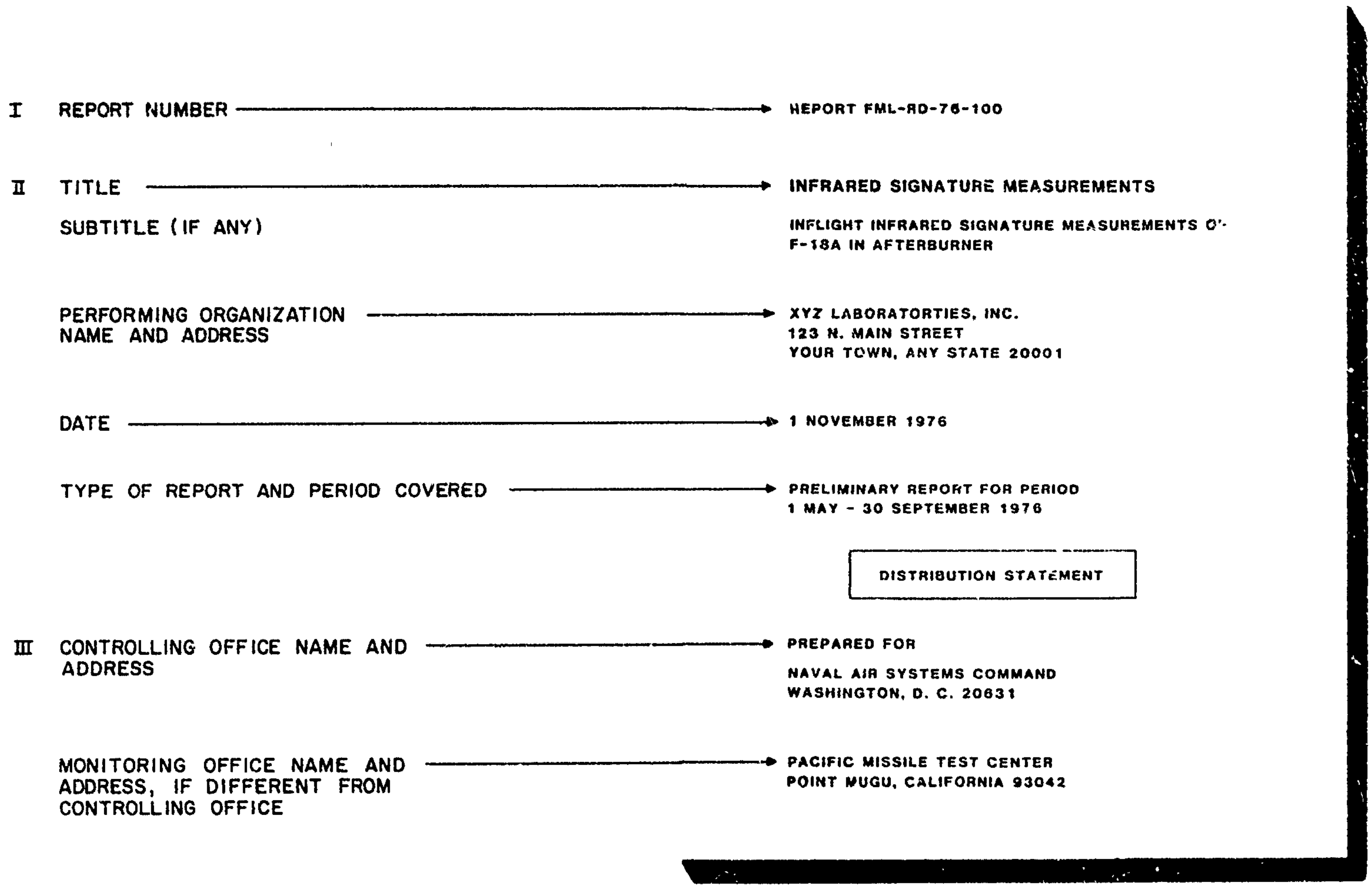

Figure 3-1. Sample of unclassified report cover. Required security markings must be added to covers of classified reports.

• Performing organization name and address. For contractor reports, give name, city, state, and zip code. List no more than two levels of an organizational hierarchy.

• Date. Each report will carry a date consisting of at least the month and year.

• Type of report and period covered. Indicate type of report, i.e., interim, final, etc., and, if applicable, dates covered.

• Distribution statement. (See DOD Directive 5200.20.) The same statement that appears here must also appear in block 16 of the Report Documentation Page, DD Form 1423.

Group III.

• Controlling office. (Equates to sponsoring/funding activity. For definition see paragraph 3.2 of MIL-STD-847A.) The name and mailing address, including zip code, will appear in the lower portion of the front cover. The words "prepared for" will be placed immediately above the sponsoring activity's name on all contractor/grantee reports.

• Monitoring agency. The name and mailing address, including zip code, will appear under the controlling office in those cases where the administrative responsibility for a project, contract, or grant has been delegated to another activity.

Inside Front Cover. A review and approval statement and special notices such as reproduction limitations, espionage, legal and supersedure information, safety precautions, sponsor's disclaimers, compliance with special regulations, or disposition instructions will be included here or on the outside front cover.

Report Documentation Page, DD Form 1473. (See figure 3-2.) Include a complete DD Form 1473 (revised), Report Documentation Page, as the first right-hand page after the cover in each report. (See Armed Services Procurement Regulation, paragraph 4-113.) Instructions for completing DD Form 1473 are contained in the appendix to MIL-STD-847A.

Summary. A summary should be included to provide a digest of the report, to explain the reason for the initiation of the work, and to outline principal conclusions and recommendations. The summary will generally be used to give more information on the content of the report than can be presented in the abstract entered on the Report Documentation Page, DD Form 1473.

Preface. If a preface is used, it may show the relation of the work reported on to associated efforts. Give credit for the use of copyrighted material, or acknowledge significant assistance received.

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

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Figure 3-2a. DD Form 1473, Report Documentation Page (front).

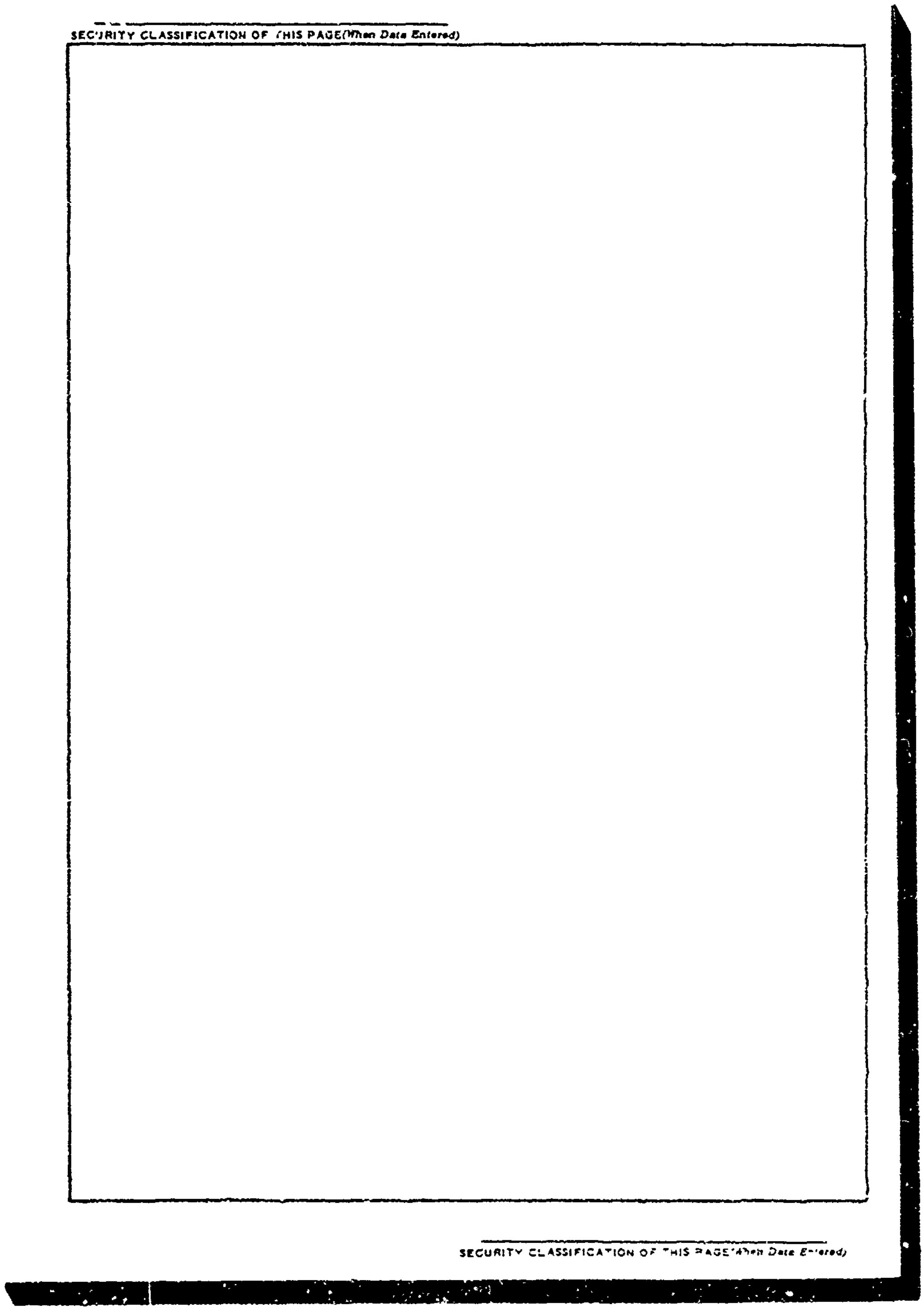
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Figure 3-2b. DD Form 1473, Report Documentation Page (back).

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List of Illustrations. Include only if considered essential. List figure number, legend or caption, and page number for each illustration. Abbreviate lengthy legends or captions.

List of Tables. Include only if considered essential. List table number, heading or title, and page number for each table. Abbreviate lengthy headings or titles.

Body of Report

General. Clients engage experimentalists to generate and report "original" data. Dictionaries equate data with information and knowledge. In order to qualify as knowledge, measurements must be accompanied by descriptions and specifications on what was being measured and how the measurements were taken. A data report must transmit knowledge, not merely measurements. Original data is far more fragile than existing data since it is lost so easily if the required descriptions are partly omitted or jumbled. Original data can be preserved and transmitted in a report only if sufficient descriptions are included so that experimental results can be reacquired successfully. Such descriptions are, indeed, a stiff requirement, a heavy responsibility for the experimentalist, and a burden for the report author.

An experimental data report author must organize his report to describe the object under test, the measurements taken, analyses conducted, measurement accuracy validation and verification, the environment in which the measurements were taken, data reduction, storage, and retrievability, data interpretation and presentation, and conclusions. As indicated in MIL-STD-847A, the author should format his technical presentation as follows:

- Introduction
- Conclusions
- Recommendations
- Main Text

Headings should stand out from the text with their relative importance apparent. Number headings and paragraphs only when needed for clarity.

Introduction. The introduction ought to begin with the reason this investigator (identity) was engaged, why the test plan is what it is, and how this experimental program relates to the mission of the test object, of the client, and of the test organization. If several organizations are cooperatively involved, the role of each in the test program should be clarified here. The introduction should constitute a technical value statement which relates the timeliness and appropriateness of this experimental program to the endeavors of the client and the benefit to the general knowledge (data base). Write the introduction so that it together with the conclusions can stand alone as a management summary report and so that it can be inlaid as a section into summary reports to be written by the client. In format, set the introduction on its own right-hand facing page.

Conclusions. The conclusions should be a brief summary of the new technical knowledge and its meaning contributed by this test program. If the test program was even partially unsuccessful, summarize the problems and difficulties, including "lessons learned."

Recommendations. Use recommendations to point out persisting voids in the overall data bank for the subject item under test, if known, or applications for the data provided in the report. It is permissable to offer further cooperation and availability of facilities but poor practice to critique client's program planning unless the critique is limited to "lessons learned."

Main Text. The main text is to be strictly technical and it must contain two basic quantities--the measurements and the specifications--each in exquisite detail. Keeping in mind that this test may someday be repeated, provide the information as follows:

Test Plan. Cover first in detail the test plan as to its objectives, strategy, and event sequence. Use charts, tables, etc., as appropriate.

Object Under Test. All measurements have meaning only when relevant to the object being measured. In the case of an aircraft, identify and describe the aircraft, model number, serial (tail) number, engines (model and serial), aircraft configuration, engine power, fuel flow, rpm, special onboard instrumentation, quantities monitored, etc. Use charts, figures, photographs, tables, etc. as appropriate. A few pages from the aircraft and engine specifications with call-outs denoting operational points would be welcome specification information. (Often these sheets can be acquired from the client along with the test plans.)

Analytical Efforts. Describe the analyses conducted to predict the experimental results. Identify computer programs used and reference their documentation. Analytical results are typically used in two ways: to set gains on instruments and to accompany measurements in the data presentation.

Test Description. Describe the test environment, test object manipulations, instrument complex, and procedures for each data point.

• Environment. The environmental data consists of date, time, temperature, pressure, humidity, carbon dioxide concentration, sky condition, background description, and photographs. If the test involves long (greater than 100 meters) optical or transmission paths, the environment should be described at the target location and also at the instrument location.

• Test object manipulation. If the target is flying, describe its flight paths (altitude, speed (Mach), flight path slope, weight, configuration, power setting, and acceleration) with photographs to show detail.

• Instrument complex. Designate the instruments (by number) assembled for each measurement complex. Use photographs for clarity and special detail.

• Test procedure. This is to be a description of how each data point was performed as to fly-by details, recording times, repetition rates, and azimuth and elevation variations (relative to target).

Calibration. Describe in general terms the calibration assumptions and procedures. Include the fine details of calibration of each instrument either in a separate reference or in an appendix. Each instrument system (including optics) should be identified by number. This identification is to be used in the description of the instrument complex and in the calibration log. Instrument build-up photographs should also be a part of the calibration log.

Data Reduction. Describe the data reduction, data analysis, and data interpretation. Data reduction should be described to transmit an understanding of how data or knowledge is developed from the various measurements taken, i.e., treatment of transmission and background to develop source emissions. Data analysis might be an accuracy analysis or comparison of redundant measurements. Data interpretation would include the derivation of unmeasurable items by indirect measurements, i.e., engine airflow from rpm measurements.

Data Presentation. It is to be reemphasized here that information (data) is being presented and not simple measurements. In order for the meaning to carry, appropriate labels, callouts, keys, specifications, etc., must be included in each chart, table, graph, and plot. Techniques for tabulation and coding these data elements are suitable.

Reference Material

References and Bibliography. Include complete identification of references on bottom of page where first cited (i.e., Footnote) to aid in reading from microform. When references are numerous, they should be repeated in a reference list in the back of the report. Arrange bibliographic entries not included in the text but supplied as supplementary information under "Bibliography." Present entries in a uniform style. Include authors, titles, sources, identifying numbers, publication dates, and applicable security classifications.

Appendices. When one or more appendices are used, designate them appendix A, appendix B, etc. Number figures, tables, and equations with the letter designation of the appendix in which they fall. Each appendix will be titled. Start each appendix on a new page.

Glossary of Terms. Define unusual terms and their units either in the text or as a footnote the first time they are used in the text. When many such terms and units are used, list them in alphabetical order with definitions and units in a glossary.

Abbreviations, Acronyms, and Symbols. Define abbreviations, acronyms, and symbols when first introduced in the text. If they are numerous, include a list of definitions in the reference material.

Index. If an index is included, make it as complete as the nature of the report and its probable usage require.

Distribution List. A distribution list may be included within a report. If included, it will appear at the end of the report.

Back Cover.

The back cover for unclassified reports can be plain with no markings. The back cover for classified reports will be marked with the appropriate security classification.

ILLUSTRATIONS

General

Treat illustrations consistently throughout a report. Prepare them so that details and callouts (labels) will be clearly legible after final reduction. To minimize continual referral to text, data charts, graphs, and data plots should contain sufficient information so that they stand on their own. Refer to chapter 4, Data Format, for further guidance.

Placement

Locate illustrations as near as possible after the first text reference except in special situations, such as a report containing a few text pages and many illustrations.

Callouts (Labels)

So far as practical, place callouts horizontal, unboxed, and near the item called out as shown in figure 3-3.

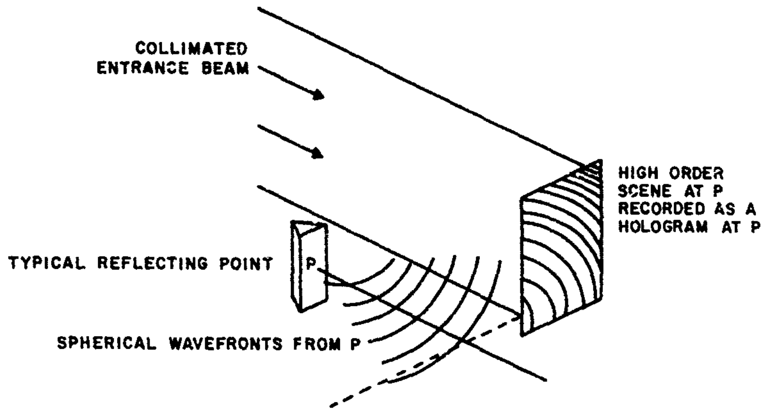


Figure 3-3. Placement of callouts in illustrations.

Color

Color will not be used unless specifically authorized by the controlling office as the only means of presenting data clearly. Figure 3-4 shows some techniques that offer effective substitutes for color.

Foldouts

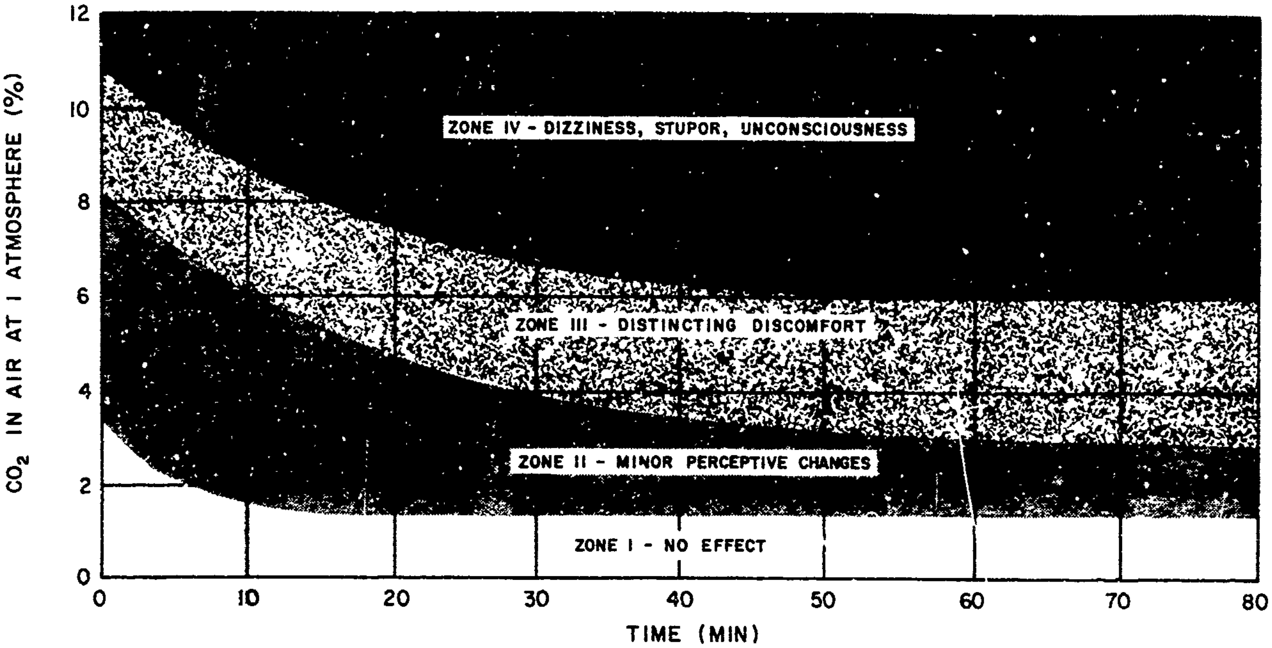
Wherever possible, avoid the use of oversize illustrations that must be folded.

Numbering

Use Arabic numerals preceded by the word "Figure" for illustrations referenced in the text. Number illustrations within appendices in a manner consistent with the appendix designation.

Legends

Accompany each illustration, except self-explanatory sketches, by a descriptive legend. Place the legend under the illustration following the figure number.



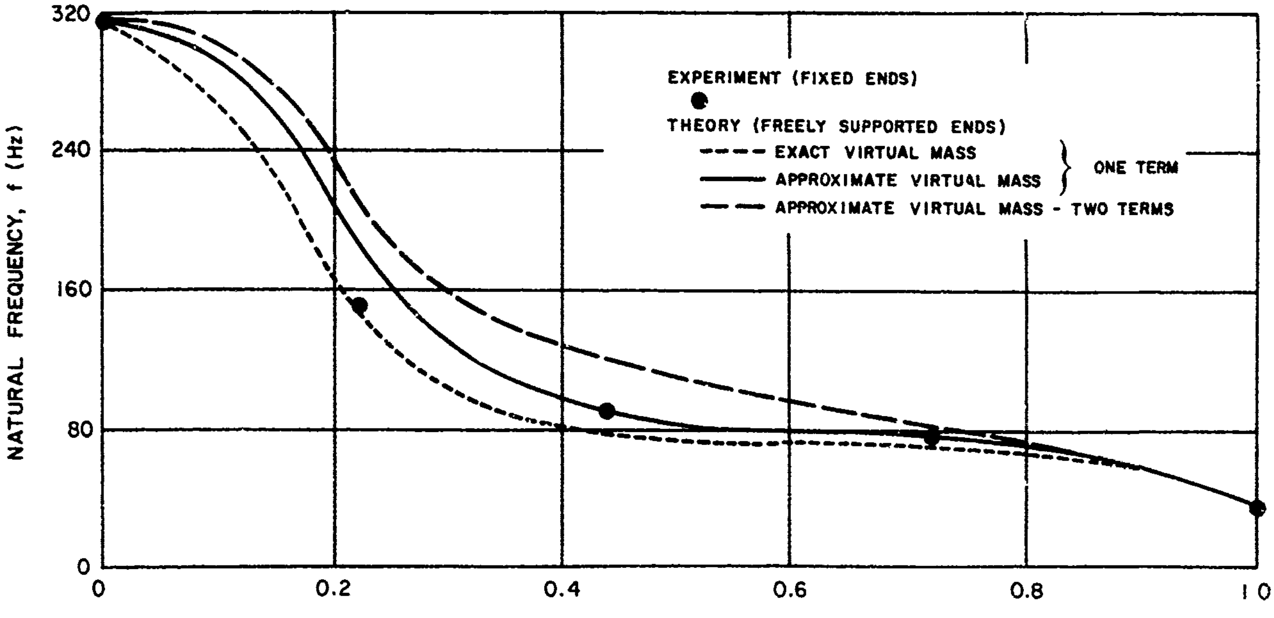


Figure 3-4. Screening (top) and coding (bottom) used as substitutes for color.

TABLES

General

Tables should be kept simple so that the reader can easily grasp the meaning of the data. Avoid vertical and horizontal lines wherever spacing can be used effectively. Figure 3-5 shows a sample typical table layout that should be used in ir technical reports.

Placement

Locate tables as near as possible after their first text reference except in special situations, such as when a report contains only a few text pages and many tables. In such cases place the tables in numerical sequence in the back of the report. Unless it is not possible to do so and maintain readability, place tables so that they may be viewed without rotating the page. If this is not possible, place each table so that it can be read by rotating the page clockwise.

Columns and Column Headings

Give applicable units of measure or degree in the column headings of tables. Do not repeat in the columns. When tables continue on two or more pages, note the continuation and repeat the column headings and rules on each page. Column headings need not be repeated on the second page for continuations on two facing pages turned sideways.

Numbering

Number tables in the text consecutively in Arabic numerals, preceded by the word "Table." Tables within appendices should be numbered in a manner consistent with the appendix.

Headings

Give each table, except short ones run in with the text, a descriptive heading following the table number. Place heading above the table.

EQUATIONS

General

Prepare mathematical matter with extreme care. Use machine or transfer-type composition when available. When necessary, identify symbols after first use in order to simplify reading from any type of microform, otherwise include in a separate list. Make opening and closing parentheses, brackets, and braces the same height as the tallest expression they enclose. Separate the numerator from the denominator with a line as long as the longer of the two. Center both numerator and denominator on the line.

TABLE 1. SHORT-TITLE XXXXXXXXXXXXXXXXXXXX ←—— Heading

Boxhead

Footnote reference

Temperature (K)	Specimen type[a]	Ultimate tensile strength (N/m^2)	Elongation between buttonheads (cm)	Reduction of area (%)
		Tungsten		
1700	1	2200×10^3	1.57	95
1900	1	1312	1.60	75
2060	1	987	0.69	36
2260	1	674	0.51	25
		Molybdenum		
1650	2	9301×10^3	0.95	96
1922	2	4068	1.55	99
2255	2	1472	1.75	99

[a]Recrystallized at 2370 K for 1/2 hour in vacuum. ←—— Footnote

Figure 3-5. Typical table layout.

Placement

Indent or center a displayed equation in the line immediately following the first text reference made to it. Break equations before an equal, plus, or multiplication sign. Align a group of separate but related equations by the equal signs and indent or center the group as a whole. Short equations not part of a series or identified by number will be placed in the text rather than displayed.

Numbering

Number equations which are part of a series or which are referred to in the text consecutively in Arabic numerals. Enclose each number in parentheses at the right margin on the last line of the equation to which it refers. Equations within appendices should be numbered in a manner consistent with the appendix.

2

CHAPTER 4

DATA FORMAT

Dan Powlette

INTRODUCTION

Have you ever tried to compare two pointance (intensity) plots of the same aircraft under apparently similar flight conditions but measured by two different facilities? After replotting the data because of scale differences were you faced with the problem of different spectral bands and different slant ranges? In the following pages recommendations will be given for standardizing both plotting format and integration bands. Environmental conditions suggested can be used to correct spectral data for differences in absolute humidity, visual range, slant range, etc.

In order to facilitate comparison of aircraft data from different reports, the pertinent information with respect to the flight/measurement conditions **should be included on the plot.** This practice will minimize the changes that the data will be taken out of context or that the data will be associated with incorrect flight/measurement conditions.

The flight/measurement conditions shown on the sample data plots are not necessarily the only ones that should appear on specific data plots. Other conditions/factors such as aircraft lights, speed brakes, special paint/coatings, active ir devices (jammers, flares), etc., may have a significant effect on the absolute or contrast target pointances.

SEMILOG BANDED AZIMUTH/ELEVATION PLOTS

An example of the apparent radiant pointance of an unsuppressed aircraft is shown in figure 4-1. The recommended pointance scale divisions of one decade per 2 inches and 50° per inch correspond to the 5 cycle Dietzgen No. 340R-L510 or K&E No. 46 213 graph paper. A maximum of 4 cycles is suggested. The ordinate scale (powers of 10) is arbitrary. The abscissa should range from 0° to 180° (nose to tail, starboard side) or 360° to 180° (nose to tail, port side) for azimuth and from -90° to 90° (directly below to directly above the aircraft) for elevation. The basic flight conditions, environmental conditions and instrument identification are included in the figure. Metric units are suggested. Tabular data corresponding to the data in each figure should be provided. Numerical values for quantities such as pointance, azimuth, elevation, and slant range for each datum point and the instrument's field of view (FOV) and relative spectral response are the minimum required information.

SEMILOG SPECTRAL PLOTS

A typical plot of the apparent spectral radiant pointance of an unsuppressed aircraft is shown in figure 4-2. The recommended pointance scale divisions are the same as those in the semilog banded plot (previously described). An abscissa scale with 1.0 micrometer per inch divisions is recommended. Sufficient information should be given on the figure to identify the spectral scan such as time and/or scan number so that more detailed pointance versus wavelength numerical values can be obtained from supplementary tables.

VISUAL PHOTOGRAPH/THERMAL IMAGE/SEMILOG SPECTRAL PLOTS

Figure 4-3 presents a data format similar to that used by General Dynamics/Pomona. The scale divisions are identical to those of figure 4-2 but only two decades are used. Tabular data should again be provided and can be used to extend the data that is outside the dynamic range of the two decade format. Radiant pointances in specific integration bands indicated by SIR-1 and SIR-2 are listed. Tabular listing of integration band relative spectral responses should be given. The location and size of the instrument's FOV relative to the target should be superimposed on the visual photograph.

LOG BANDED POLAR PLOTS

The apparent radiant pointance of a suppressed helicopter is presented as figure 4-4. The scale divisions are one decade per inch. This log polar graph paper is not commercially available but can be reproduced at each facility. It is recommended that the center of the plot begin with an odd power of ten, e.g., 10^{-1}, 10^{1}, 10^{3}, to increase the probability that two independent reports with similar test data conditions will have the data plotted on the same scale.

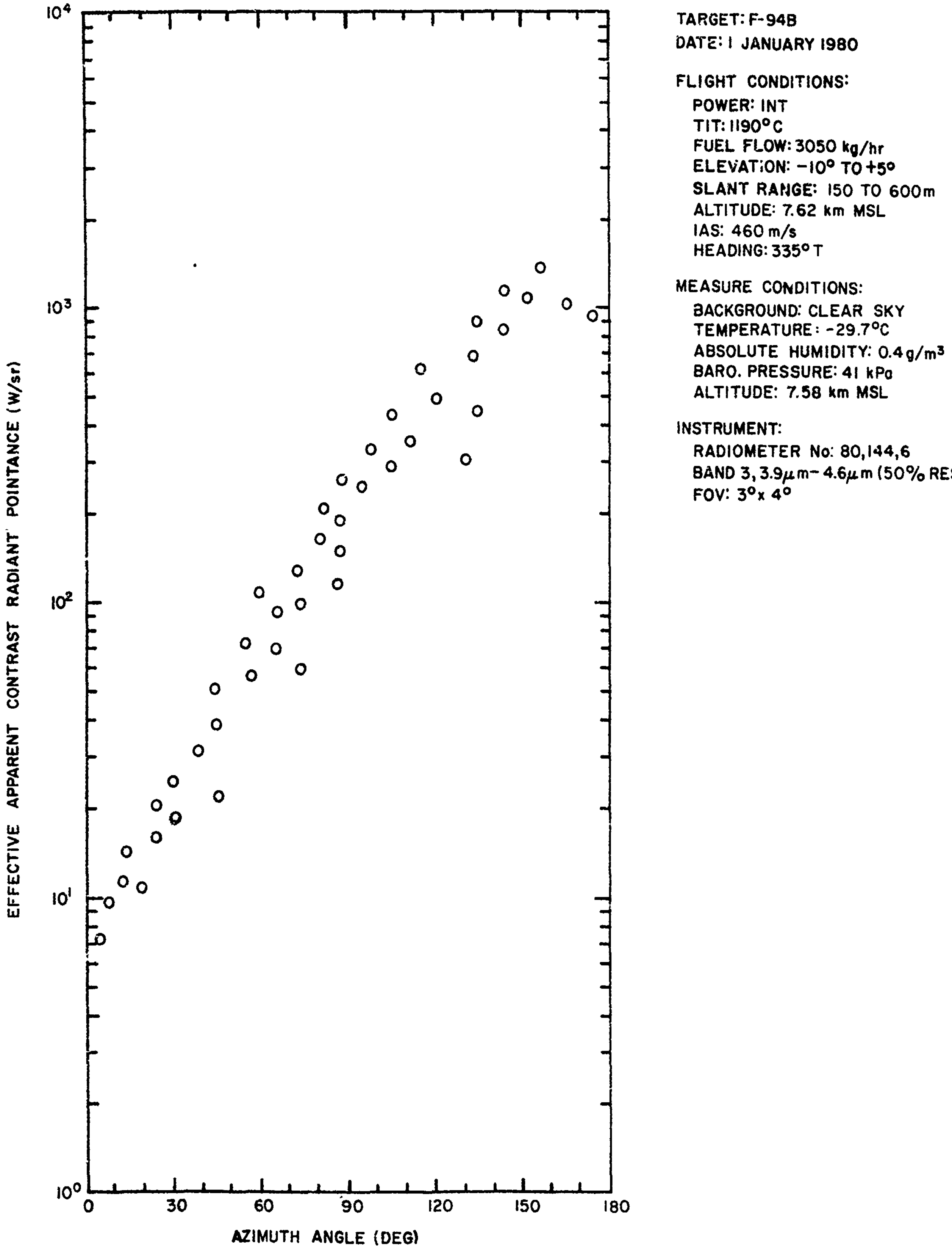


Figure 4-1. Data format for effective apparent contrast radiant pointance of an unsuppressed aircraft.

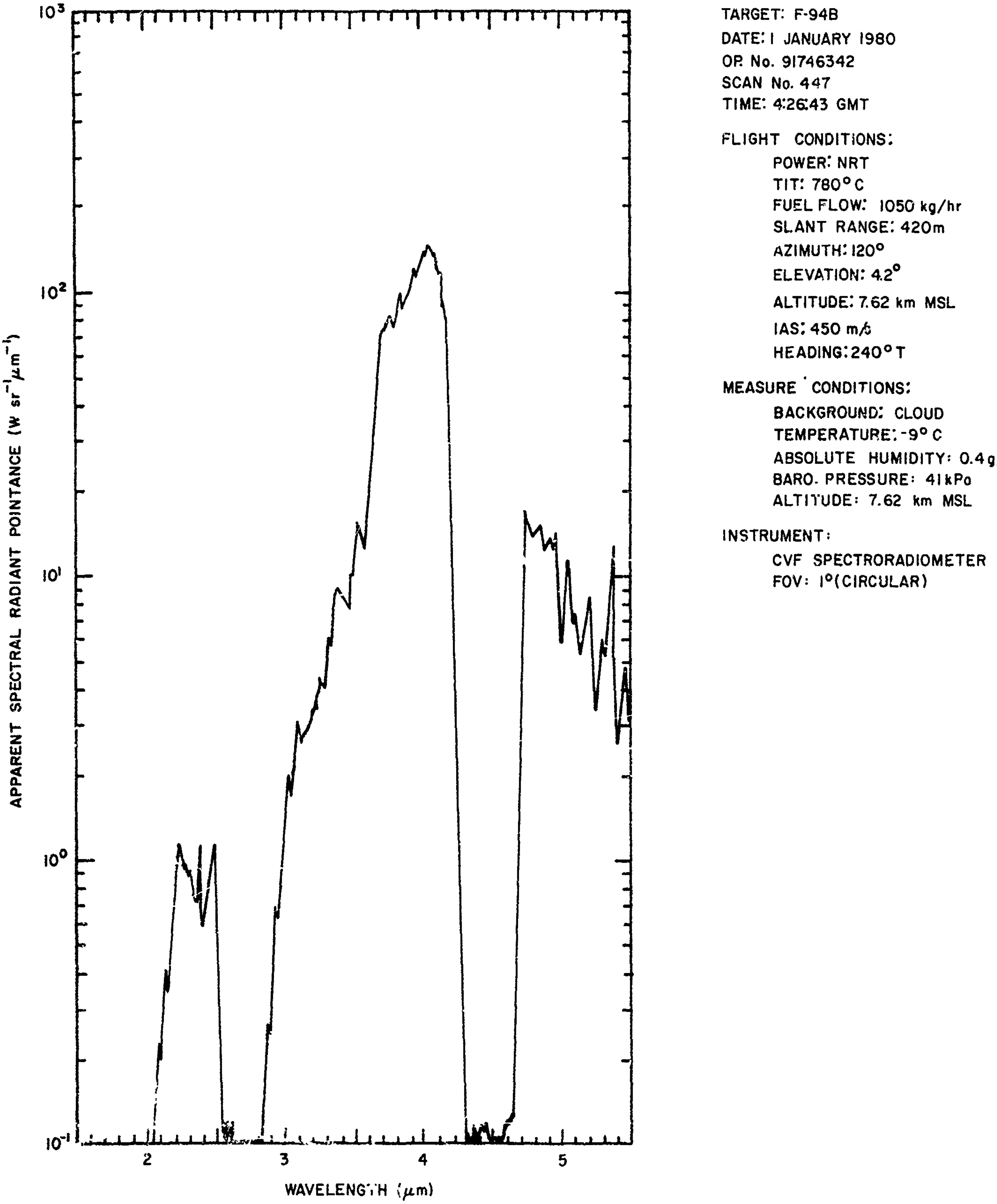
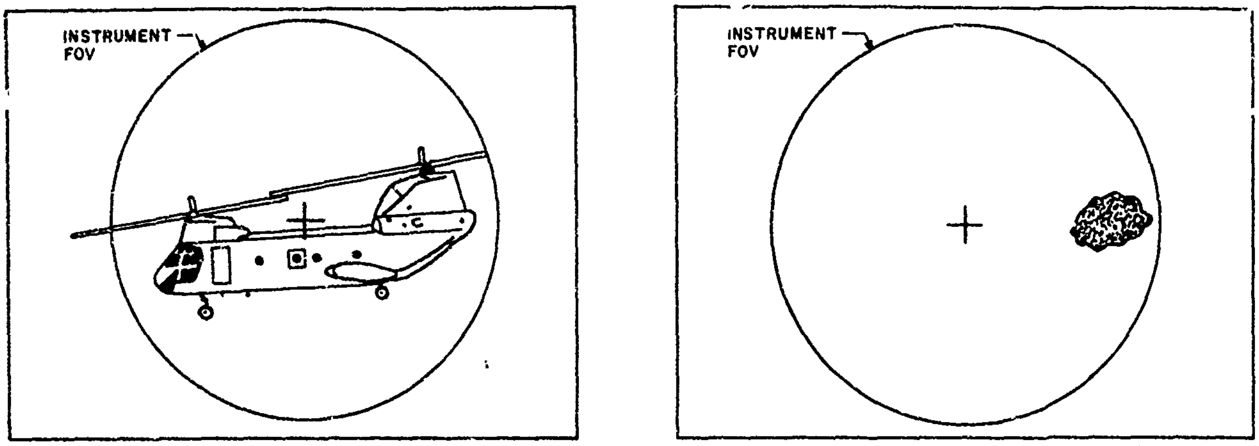


Figure 4-2. Data format for apparent spectral radiant pointance of an unsuppressed aircraft.



VISUAL PHOTOGRAPH　　THERMAL IMAGE ($2\mu m - 5\mu m$)

FLIGHT CONDITIONS:

AZIMUTH: 270°
ELEVATION: -7°
SLANT RANGE: 400 m
ALTITUDE: 50 m AGL (725 m MSL)
IAS: 0 m/s
TIT: 730°C/695°C
ENGINE RPM: 92.0/93.0%
ROTOR TORQUE: 62/63%
A/C WT: 4050 kg

MEASURE CONDITIONS:

DATE: 1 JANUARY 1980
TIME: 03:11:47 GMT
TEMPERATURE: 25.5°C
RELATIVE HUMIDITY: 31%
VISUAL RANGE: 20 km

$I_{eff\ app}$ (W/sr)
SIR-1: 2.9
SIR-2: 14.6

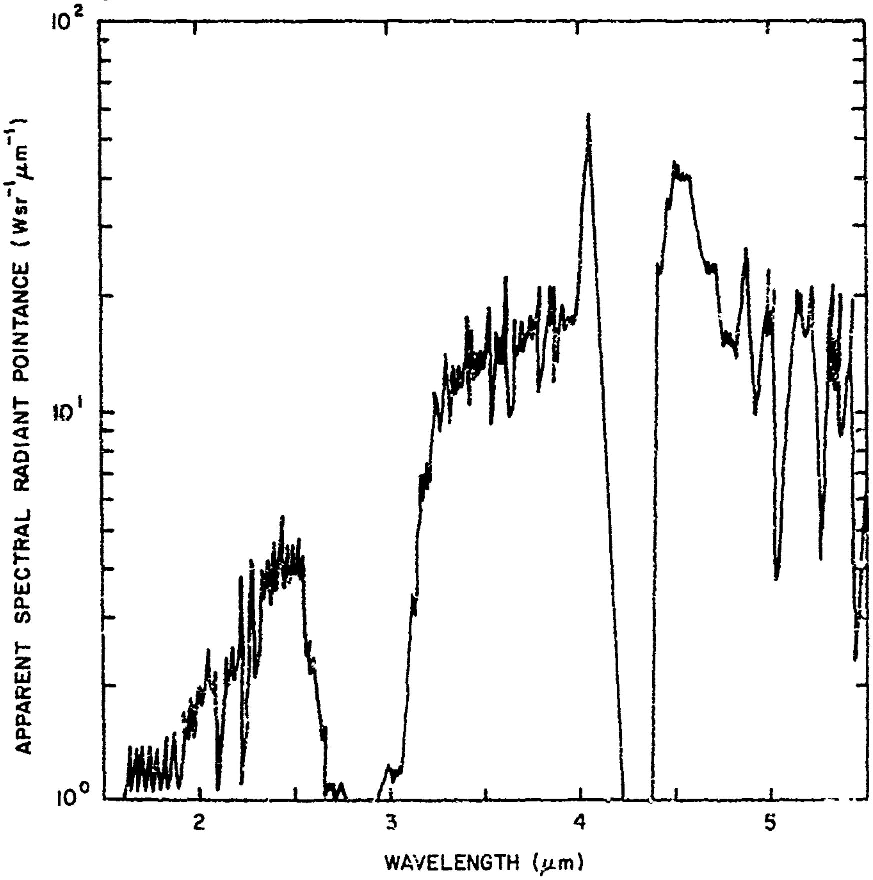
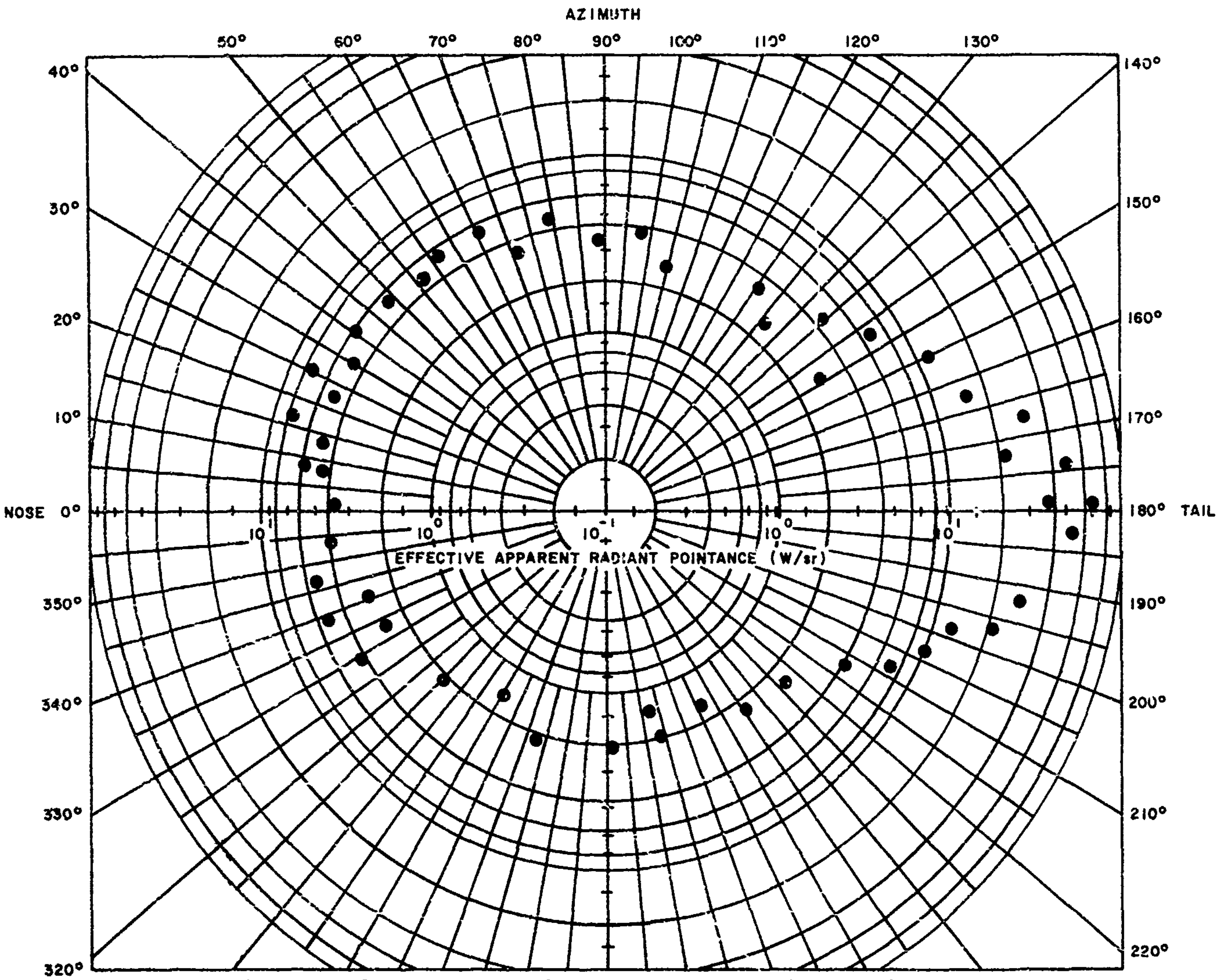


Figure 4-3. Data format for apparent spectral radiant pointance of an unsuppressed helicopter.



FLIGHT CONDITIONS:

ELEVATION: -5° TO -8°
SLANT RANGE: 250 m
ALTITUDE: 30 m AGL (705 m MSL)
IAS: 0 m/s
TIT: 760°C
ENGINE RPM: 96%
ROTOR TORQUE: 60%
A/C WT: 4000 kg

MEASURE CONDITIONS:

RESPONSE BAND: SIR-2
SUPPRESSED AIRCRAFT WITH
LOW-IR-REFLECTANCE PAINT
TEMPERATURE: 25.5°C
RELATIVE HUMIDITY: 34%
VISUAL RANGE: 20 km
BACKGROUND: OVERCAST

Figure 4-4. Data format for effective apparent radiant pointance of a suppressed helicopter.

EFFECTIVE INCIDENT RADIANT AREANCE VERSUS RANGE PLOTS

The effective incident radiant areance of an unsuppressed aircraft is given in figure 4-5. The recommended scale divisions of one decade per 2.5 inches for both abscissa and ordinate scales correspond to the 3 cycles by 3 cycles Dietzgen No. 340-L35 logarithmic graph paper.

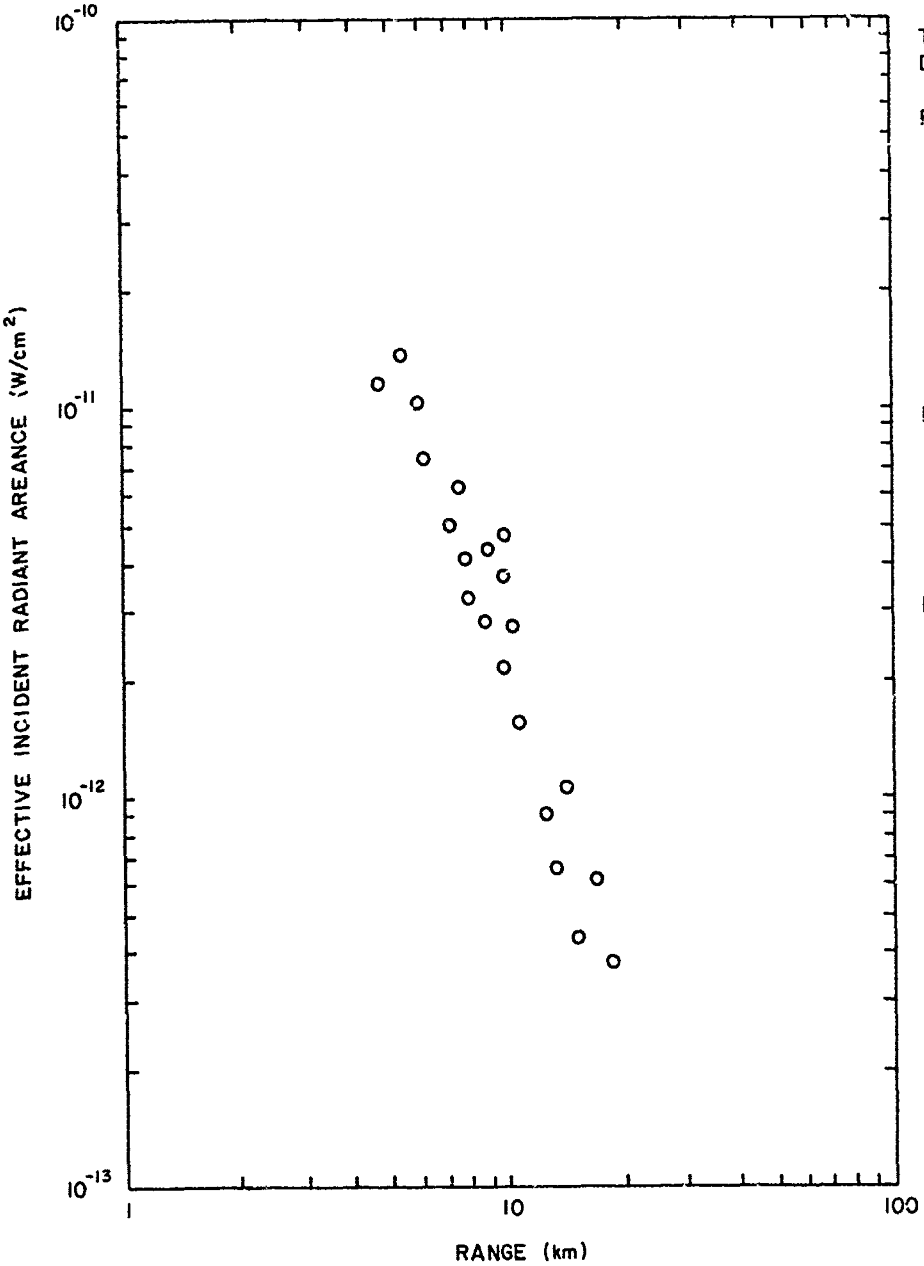
PLOTS FOR SPECIAL CASES

The use of linear pointance (versus angle or wavelength) plots may be required when plotting negative contrast or when comparing signatures covering a range greater than four orders of magnitude. Standardized data formats will not cover linear pointance plots, isometric plots, and linear wavenumber plots.

STANDARDIZED SYSTEM RESPONSE BANDS

The comparison of aircraft ir signatures would become somewhat easier if data were reported in standardized relative response bands. The use of peak normalized spectral response bands is recommended/encouraged to bring about a uniform basis for signature comparisons. The three recommended integration intervals are 2.0μm to 2.5μm, 3.5μm to 4.0μm, and 10.0μm to 11.0μm.

If additional response bands are required, tabular data and plots with an ordinate scale division of 0.4 per inch and an abscissa scale division of one micrometer per inch should be used.



TARGET: F-94B
DATE: 1 JANUARY 1980

FLIGHT CONDITIONS:
POWER: INT
TIT: 1190°C
FUEL FLOW: 3050 kg/hr
ELEVATION: -10° TO +5°
AZIMUTH: 0° TO 8°
SLANT RANGE: 150 TO 600 m
ALTITUDE: 7.62 km MSL
IAS: 460 m/s
HEADING: 335° T

MEASURE CONDITIONS:
BACKGROUND: CLEAR SKY
TEMPERATURE: -29.7°C
ABSOLUTE HUMIDITY: 0.4 g/m^3
BARO. PRESSURE: 41 kPa
ALTITUDE: 7.58 km MSL

INSTRUMENT:
RADIOMETER No: 80,144,6
BAND 3, 3.9μm - 4.6μm (50% RESPONSE
FOV: 4° x 4°

Figure 4-5. Data format for effective incident radiant areance of an unsuppressed aircraft.

CHAPTER 5

TEST PLANS

Grover S. Amick

INTRODUCTION

This chapter presents, by means of a simplified checklist, a general procedure that can be used as a guide during the preparation of test plans. For purposes of this discussion, it is assumed that the test plan is being prepared specifically for the conduct of an aircraft ir signature measurement program, although it need not be restricted to that purpose.

This description is derived for the general case and is intended to cover as many as possible of the items that warrant consideration--the concept being that if all included items are considered in terms of applicability to any test plan preparation effort, then the resulting test plan should be both complete and consistent with test plans prepared by other, independent facilities.

It is further realized that not all test programs will require all of the items described in the checklist. If, following review, the decision is made to omit an item as inapplicable, it may still be considered as having been reviewed. The checklist then serves as a guide in assuring completeness of considerations during the test plan preparation phase of an ir measurement program.

The checklist is configured generally to encourage maximum utility for broad applications; that is, very little specific background is needed to use it effectively.

The checklist evolved from an assessment of some nine individual test plans submitted by various JIRS Working Group representatives who, in turn, represent a sampling of four ir measurement facilities.

DISCUSSION

A complete test plan, fully descriptive of an ir measurement program to be conducted, must do more than describe what should be accomplished during the actual day or days of measurements. It should cover the total spectrum of activities, how they are to be accomplished, when they will take place, who will perform them, etc., with the bottom line being that it should be done on time and within allocated resources.

The test plan for an ir measurement program is a project plan. Like all project plans, the most complete and well thought out plans have the highest probability of success. Nothing drives a schedule or budget off track faster than a series of surprises. Quite often, many of these surprises can be avoided through proper test plan preparation.

Some ir measurement facilities have specific internal procedures for the development of a test plan. During our survey of available test plans and procedures, we have not identified any conflicts that would arise from using the proposed checklist in conjunction with existing procedures.

In most cases, the problems encountered in the review of the submitted test plans were errors of omissions--for example: no scheduling information, no plan for data reduction or reporting, no identification or delegation of authority. Thus, it appeared evident that the most pressing need in efforts to standardize and improve the quality of test plan preparation was not in lengthy dialogue describing precisely how to plan a project, but the development of a succinct method by which an individual could refresh himself on the points that should logically be considered for inclusion in a test plan.

TEST PLAN CHECKLIST

The Test Plan Checklist proposed is presented in table 5-1. The various section descriptions are as follows:

Section 1. Introduction

The introduction of the test plan under preparation should include a succinct statement of the work to be done and measurements to be made, title, a summary of prior or ongoing related test programs, and identification of documents or materials that would be useful to the test agency in execution of the test plan. Related program organizations and personnel should be listed by name, address, and telephone number.

Section 2. Background

This section should provide insight into the need for the test. It should indicate what testing has been done in the past or may be in progress, to satisfy the need. How this test satisfies the need where others have not, should be clearly stated.

Section 3. Test Objectives

A discussion of critical questions and issues to be answered by the test results should be given. It should be made clear in the discussion as to how the results are expected to provide the answers. Primary objectives and any subobjectives should be identified, in addition to the parameters to be measured. Minimum acceptable objectives should also be stated.

Section 4. Test Setup/Environmental Conditions

Give an overall description of the target, scenario, and environmental condition requirements for the measurements. If certain requirements are critical and/or specific, identify these. Others may be of insignificant importance; indicate this. It should be thought out and clearly stated as to what the setup and conditions of the test must be in order to obtain the required results.

Section 5. Instrumentation Requirements

Lists of the required instrumentation containing type (function), manufacturer, model number, and organization responsible for providing each instrument should be presented. Instrument characteristics pertinent to the measurements and measurement accuracy capabilities should be stated. A separate list of instrumentation and equipment for ground facilities, target test aircraft, support test aircraft, weather measurement, photographic coverage, and other (special) applications should be given. Any special frequency allocations should be presented. Availability of the instruments and supporting resources should be given.

Section 6. Test Aircraft

The model series, design, quantity and support of each type of test aircraft (target, support, other) should be defined. Organizations and personnel responsible for providing test aircraft should also be identified.

Section 7. Test Preparation and Setup

Test aircraft modifications, ground facility modifications and setup, and all necessary calibration of equipment should be described. Technical support needed to accomplish this preparation should be determined. The location of each instrument in the test setup (ground facilities, weather measurement site, test aircraft, etc.) should be specified. Indicate the time period required for the test preparation. Provisioning organizations should be identified.

Section 8. Data to be Obtained

The quantity, quality ("goodness"), format, and significance of data to be obtained should be discussed. The quality of data required should be clearly and concisely expressed with an uncertainty value or a confidence interval, and the quality so-stated should be compared with the accuracy capabilities of the measurement instrumentation given in Section 5. The significance or importance of individual data elements to the final results should also be discussed.

Section 9. Data Acquisition Procedure

Summarize the test procedure. Describe the various test configurations and provide a matrix of parameters describing variations in flight conditions (speed, altitude, stores, speed brakes, etc.). State the number of estimated flight hours as sorties. Specify all personnel required to operate the data acquisition system. State time period (start, completion dates). State minimum number of successful flights needed to accomplish primary test objectives.

Section 10. Data Reduction Procedure

List the desired resultant parameters and describe the form of their presentation. Describe the method of data reduction, including a block diagram of the process from raw data to resultant parameter(s) if possible. State the means for the selection of the portion(s) of the total raw data collected which will be used in the data reduction process and determine the degree of uncertainty or the confidence level of the resultant parameter(s). List responsible organizations and individuals involved in the data reduction (name, code, and telephone extension). Indicate the time period used for the data reduction.

Section 11. Presentation of Test Results

Identify the type(s), quantity, and content of reports to be presented. State the organizations and individuals responsible for writing, publishing, and distributing the reports (give name, address and telephone number). Include a schedule of dates of presentation of interim, letter and/or final reports and any distribution restrictions.

Section 12. Management Reporting

State the types, quantity, and content of reports to be submitted. These reports are needed for management control and visibility of the test program, especially in the areas of expenditures and support requirements. Since the needs of the Program Manager will vary between test programs, report contents should be determined from the needs and philosophy of the Program Manager. Suggested reports are the Progress/Expenditure Report and the Quick Response Report. The Progress/Expenditure Report summarizes the costs to date, estimates costs to complete the program, and discusses the relationship

between test progress and expenditures. The Quick Response Report indicates facility, aircraft, or other problems that would affect the test program schedule. The frequency and schedule of Progress/Expenditure Reports (or equivalents) should be specified. Reports are submitted by the test agency.

Section 13. Safety Considerations

All possible hazards that could endanger the safety of test equipment, personnel, real estate, surrounding areas, and population should be discussed. Any precautions and foreseeable solutions should be described.

Section 14. Environmental/Ecological Impact

A statement indicating that environmental or ecological impact has been considered should be given. If testing affects the environment or ecology, the various effects and, if possible, realistic solutions should be cited.

Section 15. Security Considerations

If the test program is performed on a contract delivered item, DD Form 254 must be attached. If this form is unavailable, test equipment, operating characteristics, and results classification must be specified.

Section 16. Administrative Facilities/Requirements

Any responsibility by the test agency for any of the following services should be described: housing, messing, transportation, vehicles, communication services, office space, controlled access, and special areas. Time periods for these services should be specified.

Section 17. Program Schedule

A complete program or milestone schedule should be provided. The schedule should range from test preparation through final report distribution. Include availability dates for equipment and supporting resources. Identify any critical milestones that must be accomplished on time in order to avoid overruns and/or delays.

Section 18. Responsibilities List

A list summarizing persons and organizations (name, code, and telephone extension) responsible for aspects of the test program outlined in this program test preparation guide should be presented.

Section 19. Coordination

Any coordination required to accomplish test program objectives should be described. Time period (start and completion dates, if possible) organizations, representatives of those organizations (described by name, address,

and telephone number), and the tasks involved in the coordination should be discussed. The method of coordination (letter, telephone, etc.) should also be specified.

SUMMARY

The Test Plan Checklist has been prepared in a general format and should not be considered as being restrictive in any sense. Its purpose is to assist the preparer in developing a complete and useable test plan. The addition of other applicable information not addressed in the test plan checklist is strongly encouraged. As stated previously, the most consistently encountered problem with respect to test plans has been the provision of too little information rather than too much information.

TABLE 5-1. TEST PLAN CHECKLIST

Areas for Consideration	Considered	Applicable	Completed
1. INTRODUCTION Title Summary of related programs Identification of reference documents Related program organizations Related program personnel Name Code Telephone			
2. BACKGROUND Justify need for test Identify prior and current similar tests and their shortcomings			
3. TEST OBJECTIVES Identify critical questions/issues List primary objectives List secondary objectives Identify parameters to be measured			
4. TEST SETUP/ENVIRONMENTAL CONDITIONS Target Part to be measured Operating condition such as aspect angle, power setting, altitude, speed, distance Scenario Ground-to-air, air-to-air flight configuration Environment Day/night Temperature Humidity Wind Haze Clouds Background			

TABLE 5-1. SHEET 2

Areas for Consideration	Considered	Applicable	Completed
5. INSTRUMENTATION REQUIREMENTS			
Ground applications			
Type			
Description			
Model number			
Supplying organization			
Target test aircraft application			
Type			
Description			
Model number			
Supplying organization			
Support test aircraft application			
Type			
Description			
Model number			
Supplying organization			
Weather measurement application			
Type			
Description			
Model number			
Supplying organization			
Photographic coverage application			
Type			
Description			
Model number			
Supplying organization			
Other (special) applications			
Type			
Description			
Model number			
Supplying organizations			
Frequency allocations			
Availability			

TABLE 5-1. SHEET 3

Areas for Consideration	Considered	Applicable	Completed
6. TEST AIRCRAFT Model and description Series Design Quantity Responsible (supplying) org. Supplying personnel Name Code Telephone Definition of "target" aircraft function Definition of "test" aircraft function			
7. TEST PREPARATION AND SETUP Aircraft modifications required (technical support needed) Ground facility modifications (technical support needed) Equipment calibration Location of instrumentation Time required (start, completion dates) Responsible organization Responsible personnel Name Code Telephone Test site location			
8. DATA TO BE OBTAINED Quantity Quality ("goodness") Format Significance of results			

TABLE 5-1. SHEET 4

Areas for Consideration	Considered	Applicable	Completed
9. DATA ACQUISITION PROCEDURE Summary of procedure Test configurations Matrix of parameters Number of flights, hours of sorties Technical support needed Time schedule (start, completion dates)			
10. DATA REDUCTION PROCEDURE Desired resultant parameter(s) Form of presentation Method of reduction Summary of steps in process Frequency (portion) of data used "Goodness" of results required Procedural block diagram Time schedule (start, completion dates)			
11. PRESENTATION OF TEST RESULTS Type(s) of reports Interim Letter Final Quantity Content Schedule Responsible organization/individuals Writing Publishing Distributing			
12. MANAGEMENT REPORTING Suggested management reports Progress/expenditure Quick response Responsible Organization Code Telephone			

TABLE 5-1. SHEET 5

Areas for Consideration	Considered	Applicable	Completed
13. SAFETY CONSIDERATIONS Identification of potential hazards Precautions/solutions			
14. ENVIRONMENTAL/ECOLOGICAL IMPACT Statement of impact consideration Effects of test on surroundings Potential solutions			
15. SECURITY CONSIDERATIONS DD 254 included Listing of classified material Test equipment Operating characteristics Results/data			
16. ADMINISTRATIVE FACILITIES/ REQUIREMENTS Housing and messing Transportation and vehicles Communications services Office space Controlled access and special areas Time periods for services			
17. PROGRAM SCHEDULE Milestone schedule Availability of resources Identify critical milestones			
18. RESPONSIBILITIES LIST Names of key individuals/ organizations Address Telephone numbers			
19. COORDINATION Procedure Timing (schedule) Method Involved organizations			

CHAPTER 6

CALIBRATION

Dan Stowell

INTRODUCTION

The calibration of an ir measurement system is a critical first step in the measurement process. An adequate and accurate calibration is essential to establish a data base which will provide confidence in the test data and also a basic understanding of the data. This chapter will summarize the various calibrations required to understand the instrumentation, recommend calibrations, discuss techniques, and examine mathematics of radiometry.

Radiometry is a field which has been seldom taught in any depth. As a result, individuals in the field become educated through reading reports and books and through experience. It has been largely a field entered through a self-study process after gaining a basic background in physics and electromagnetic theory. This fact is largely why Henry Koskowski and Fred Nicodemus of the National Bureau of Standards are publishing a self-study manual on radiometry. This manual promises to be the most complete and comprehensive treatment of the subject of radiometry thus far written. There have been numerous good books and reports written which cover various aspects of radiometry. A bibliography is provided at the end of this chapter which lists much of the literature available on radiometry. The reader should refer to these references for detailed discussions in the various areas of radiometry.

The primary source of formal education in radiometry for many years was through the University of Michigan. Other schools, such as the University of Rochester, the University of Arizona, and Utah State University are now offering complete programs in the field of electro-optics.

RADIATION AND RADIOMETRY

The radiometer is a device for measuring radiant flux. Figure 6-1 illustrates the complex problem of measuring the radiant flux emitted by a target in a typical environment. There are various other sources contributing radiant flux with an intervening atmosphere scattering, reflecting, and absorbing the radiant flux as well.

The target (source of interest) can be characterized in four domains: spatial (position or geometrical extent), temporal (time variations), spectral (wavelength or optical frequency distribution), and polarization. The calibration must characterize the sensor in these domains.

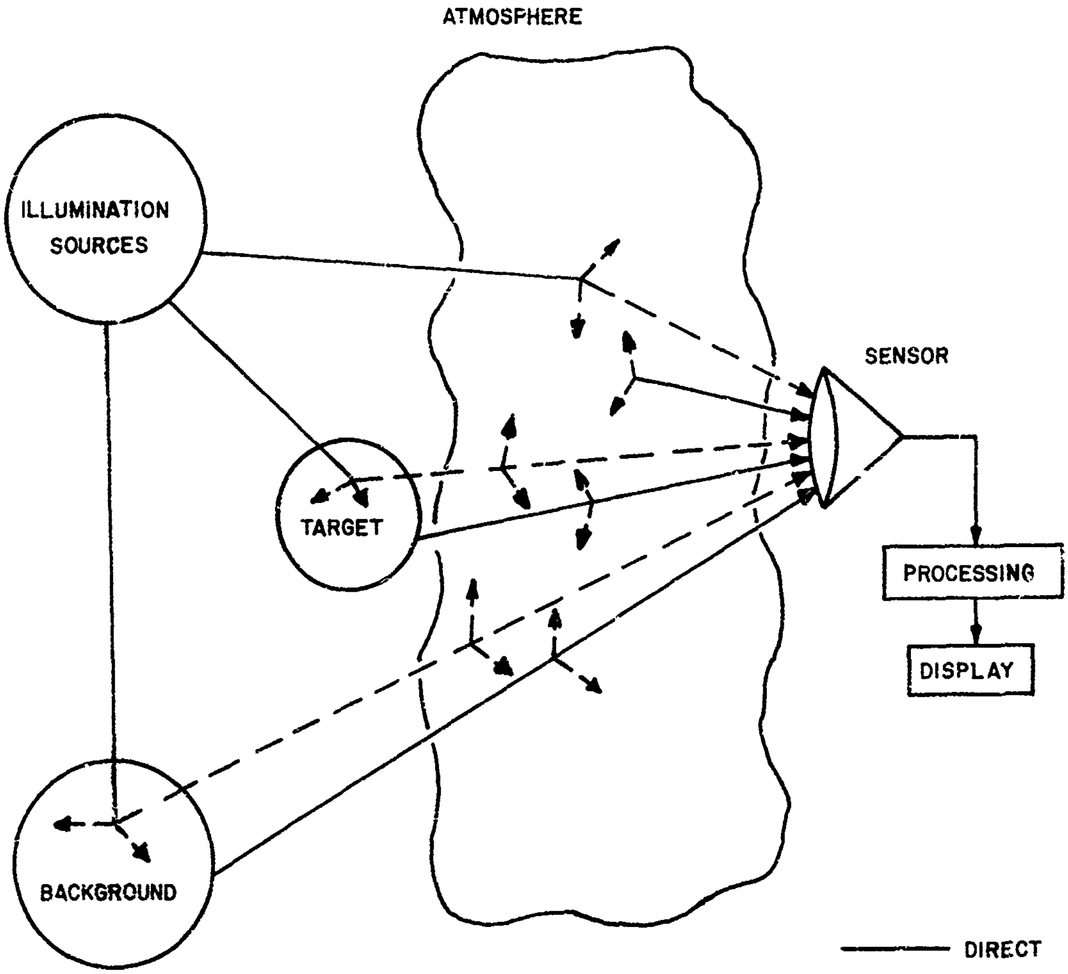


Figure 6-1. Radiant flux measurements.

The objective of a calibration should always be to make the measurement results independent of the instrument and measurement technique. The same results should be obtained when another instrument and/or technique is used to measure the same quantity. The calibration should also be conducted under conditions which will reproduce, as nearly as possible, the exact measurement conditions.

The following areas of radiometry are of primary interest in this guide: Spectroradiometry is concerned with measuring how radiant power is distributed with respect to the wavelength or the frequency of the radiation. Filter radiometry or radiometric measurements with spectrally selective instruments are also concerned with spectral distribution, but with coarser resolution into broad spectral bands or regions. Temporal radiometry (so-called ac radiometry) is the measurement of the radiant power in a time-varying beam of radiation and of the distribution of the frequencies and amplitudes at which the variation or modulation is taking place. Spatial radiometers are used to measure the way in which radiant power is distributed in position or in direction.

BLACKBODY RADIATION

A primary technique for the calibration of radiometric instruments is to record their response to blackbody radiation. Blackbody simulators are used as primary standards and other simulators are calibrated to be traceable. These blackbody simulators are typically accurate to less than one percent in approaching an ideal blackbody. The ideal blackbody is completly opaque and nonreflecting in all directions (at all wavelengths) and radiates uniformly in all directions (isotropic). Blackbody spectral radiant sterance (spectral radiance) (L_λ) is described by Planck's equation:

$$L_\lambda = 2\,\frac{hc^2}{\lambda^5}\left[\frac{1}{\exp(hc/\lambda kT) - 1}\right]\ \mathrm{W\ m^{-2}\ sr^{-1}\ m^{-1}}. \qquad (6\text{-}1)$$

where

h = Planck's constant = 6.6262×10^{-34} J s,

c = velocity of light = 2.9979×10^{8} m/s,

λ = wavelength (in vacuum) m,

k = Boltzmann's constant = 1.3806×10^{-23} J/K, and

T = absolute temperature K.

Figure 6-2 shows the spectral radiant sterance calculated from Planck's equation for various blackbody temperatures. The derivative of Planck's equation with respect to wavelength gives the **Wien displacement law** which relates blackbody temperature to the wavelength of maximum spectral radiant sterance.

$$\lambda_m = 2898/T \, \mu m. \tag{6-2}$$

The more rapid change in spectral radiant sterance with respect to wavelength at wavelengths below λ_m indicates the desirability of using a calibration source temperature which has a λ_m less than the wavelengths of concern in the calibration. This course will also lessen the impact of blackbody temperature errors on the calibration.

The **Rayleigh - Jeans law** approximates Planck's law (at long wavelengths) for the conditions $hc/\lambda kT << 1$.

$$L_\lambda \approx \frac{2\,ckT}{\lambda^4} \; W\,m^{-2}\,sr^{-1}\,m^{-1} \quad . \tag{6-3}$$

Wein's radiation law approximates Planck's law (at short wavelengths) for the conditions $hc/\lambda kT >> 1$.

$$L_\lambda \approx \frac{2\,hc^2}{\lambda^5} e^{-hc/\lambda kT} \; W\,m^{-2}\,sr^{-1}\,m^{-1} \quad . \tag{6-4}$$

The Wein expression is accurate to within one percent at wavelengths up to the maximum of the spectral curve and the Rayleigh-Jeans expression has comparible accuracy when $\lambda T > 7.7 \times 10^5 \, \mu m \, K$.

The **Stefan - Boltzmann law** gives the total radiant exitance (M) from a graybody as:

$$M = \varepsilon \, \sigma \, T^4 \; W/m^2 \tag{6-5}$$

where

ε = total hemispherical emissivity ($\varepsilon = 1$ for blackbody case) and

σ = Stefan - Boltzmann constant = $5.6696 \times 10^{-8} \, W\,m^{-2}\,K^{-4}$.

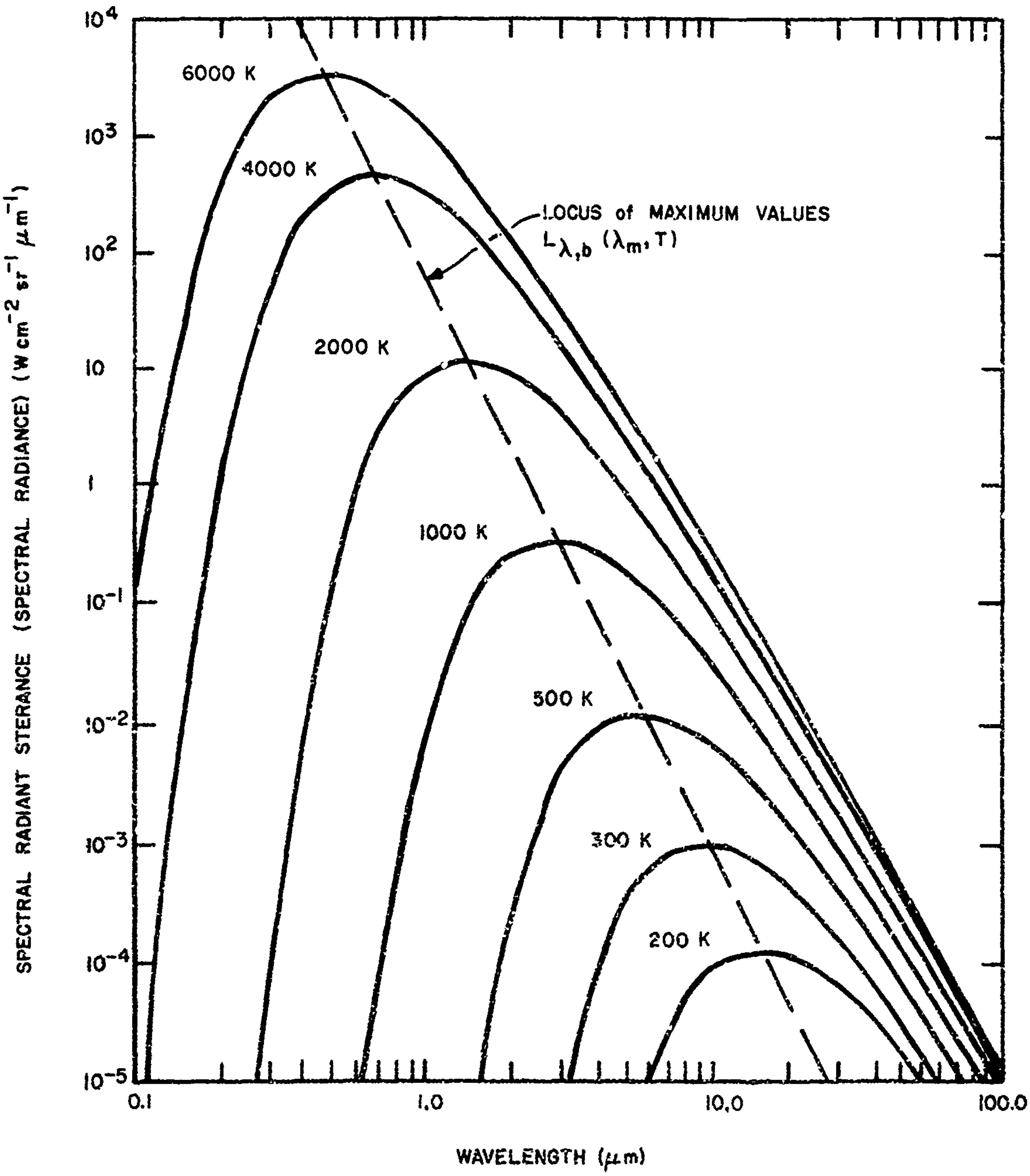


Figure 6-2. Blackbody spectral radiant sterance (Planck's law).

Kirchhoff's law states that the absorptivity, α, of a surface is exactly equal to the emissivity of that surface.

$$\varepsilon(\theta, \Phi) = \alpha(\theta, \Phi) = 1 - \rho(\theta, \Phi; 2\pi) \tag{6-6}$$

where

ρ = reflectance.

Lambert's cosine law states that the radiation per unit solid angle radiant pointance (radiant intensity, I) from a given area of a perfectly diffuse surface varies as the cosine of the angle between the direction of interest and the normal to the surface. This is true only for point source conditions.

$$I = I_0 \cos \theta \text{ W/sr} \tag{6-7}$$

RECOMMENDED CALIBRATIONS

It is critically important that certain characterizations of data be provided in any report. This is an attempt to prevent misuse of the data. An important part of the data characterizations required is a specification of the instrument used to gather the data. This specification includes physical descriptions of the instrument and how it was used, calibration procedures and results, and methods of recording and presenting the data. Table 6-1 is a checklist of general specifications which should be provided in a report. These specifications (along with all calibration records) should also be kept in an instrument logbook.

Polarization is generally ignored in most radiometric calibrations, but this may be an important consideration. Tests should be performed to determine instrument response to polarized radiation. Polarization aspects are treated in great detail in a chapter of the National Bureau of Standards, self-study manual on radiometry.

Radiometers

For a radiometer, the following specific calibrations should be performed in the laboratory and recorded in the instrument logbook before and after each series of tests:

1. Field of view (FOV) uniformity test (provide map).

TABLE 6-1. CALIBRATION CHECKLIST

	Radiometer	Spectrometer	Imager	Seeker
Instrument specifications (fixed)				
Optical system material/coatings	X	X	X	X
Entrance aperture	X	X	X	X
f/no	X	X	X	X
Detector (type, size, cold stopped, cooling, temperature control, number)	X	X	X	X
Number of gain/attenuation channels	X	X	X	
Optical/mechanical layout	X	X	X	
Gimbal limits (field of regard)				X
Effective aperture				X
Type of signal processing and tracking				X
Instrument operating parameters				
Type of chopping/frequency/reticle design	X	X		X
Internal reference source characteristics	X	X	X	
Linear dynamic range in each gain channel	X	X	X	
Scan pattern			X	
Stability (short and long term)	X	X	X	X
System electronic frequency response	X	X	X	X
NEI (noise equivalent irradiance) (define minimum reduceable signals)	X		X	X
NESI (noise equivalent spectral irradiance) (define minimum reduceable signals)		X		
Environmental effects (altitude, temperature, humidity, etc.)	X	X	X	X
Instantaneous FOV				X
Spectral characteristics				
Number filters	X		X	
Filter wheel layout	X		X	
Filter wheel scan rate	X		X	
System spectral response for each filter	X		X	X
Spectral scan rate		X		
Spectral limits		X		
Spectral resolution		X		
Spatial characteristics				
FOV-uniformity	X		X	X
Number of data elements/resolution per element			X	
Time/frame or field-lines/frame, elements/line			X	
Spatial resolution (attenuation as a function of target size)			X	
Polarization response	X	X	X	X
Data specifications				
Recording equipment formats	X	X	X	X
Output formats	X	X	X	X
Processing and reduction techniques	X	X	X	X

2. Incident radiant areance (irradiance) responsivity test (in a nitrogen environment). Document the output signal as a function of incident radiant areance for the entire dynamic range.

3. Spectral response--must be of total system response in a nitrogen purged environment (for all bands).

4. System (radiometer and pointing device) boresight test.

5. Measurements of system output signal drift and day-to-day repeatability.

Field calibrations should include the following tests before or after (or both) each series of measurements:

1. Coarse check of FOV uniformity to assure radiometer is in proper alignment.

2. Boresight check.

3. Responsivity check (tests for any change from laboratory calibration) at primarily one incident radiant areance level in a nitrogen environment (ideally) or in band where no atmospheric absorption is present. The nitrogen environment is generally too difficult for field tests.

4. Site effects check (background and environmental).

As mentioned above, a logbook or detailed records must be kept on each instrument to keep track of performance and all modifications.

Spectrometers

Specific calibrations that should be performed in the laboratory are:

1. FOV uniformity test (provide map).

2. Spectral incident radiant areance responsivity test (in a nitrogen environment) and give sample curves at selected wavelengths. Multiple incident radiant areance levels are required to cover dynamic range and to show linearity.

3. System response of total system in a nitrogen environment.

4. Boresight test of spectrometer and its pointing device.

Field calibrations should include the following tests before or after (or both) each series of measurements:

1. Coarse check of FOV uniformity to assure spectrometer is in proper alignment.

2. Boresight check.

3. Site effects check.

4. Spectral responsivity check at primarily one incident radiant areance level to provide check on system gain change from laboratory calibration (data will be compared in areas where atmospheric absorption is not present).

Spatial Radiometer

Specific calibrations that should be performed in the laboratory for a spatial radiometer are:

1. Incident radiant areance responsivity test (in a nitrogen environment ideally) for all bands of levels which cover entire dynamic range and spatial response mapping.

2. Spectral response of total system for each band filter measured in a nitrogen purged environment.

3. System (radiometer and pointing device) boresight test.

4. Measurements of system output signal drift and day-to-day repeatability.

Field calibrations should include the following tests before or after (or both) each series of measurements:

1. Check of system boresight.

2. Responsivity check at primarily one incident radiant areance level to provide check on system gain change from laboratory calibration. This test would ideally be done in a nitrogen environment or use a band filter in a wavelength region not affected by atmospheric absorption.

3. Site effects check

Seekers (Nonimaging)

Specific calibrations that should be performed in the laboratory on nonimaging seekers are:

1. Incident radiant areance responsivity test (in a nitrogen environment) for seeker configured as a radiometer. Seeker used for evaluating guidance performance must be tested on a rate table to determine tracking rate as a function of incident radiant areance and signal to noise.

2. Spectral response of the seeker must be determined in a nitrogen purged environment.

3. Automatic gain control (AGC) and static gain curve tests.

4. Seeker boresight to pointing or related devices.

5. Measurements of seeker signal output drifts.

Field calibrations should include the following tests before or after (both) each series of measurments:

1. Boresight check.

2. Site effects check.

3. Responsivity check at primarily one incident radiant areance level in a nitrogen environment (ideally) or in band where atmospheric absorption is not present. (This is a check on system gain change from laboratory calibration.)

General Comments

Blackbody temperatures should be periodically checked with thermocouple probes. Regions of stable operation should be known. Blackbodies and standard lamps should be sent to standard laboratories for annual calibrations and should be checked before each use. Several laboratories throughout the United States calibrate these sources. There is a joint tri-Service standards coordinating group located at each facility listed below. The National Bureau of Standards Radiometric Physics Division is another excellent source of help.

Joint Tri-Service Standards Calibration Coordination Groups

Infrared and Laser Standards Laboratory, MLW
HQ 2802d Inertial Guidance and Calibration Group (AFLC)
Newark Air Force Station
Newark, Ohio 43055
Telephone: (614) 522-7695 or 7324 (alternate)

US Army Missile Command
AMSMI - MMM
Redstone Arsenal, Alabama 35809
Telephone: (205) 876-1986

Naval Plant Representative
Metrology Engineering Center
General Dynamics Pomona Division
1675 W. 5th Avenue, P. O. Box 2507
Pomona, California 91766
Telephone: (714) 629-5111

National Bureau of Standards
Radiometric Physics Division
Gaithersberg, Maryland
Telephone: (301) 921-3613
Mail: A223 Physics Building NBS
Washington, D. C. 20234

All blackbody sources used for calibration purposes must be National Bureau of Standards traceable.

It is emphasized that a collimated source is recommended for calibration of optical systems. All basic calibrations should be performed in nitrogen environments to avoid atmospheric attenuation. All spectral response measurements should be for the total system. Precise voltage calibrations are required for all analog recording techniques.

CALIBRATION TECHNIQUES

The basic relationship between the incident radiant flux and the sensor output is usually a constant factor referred to as the instrument responsivity. This factor relates the sensor output (typically in volts) to the radiant flux, the incident radiant areance, or the radiant sterance at the sensor aperture. The calibration relationship used most often is the incident radiant areance responsivity which is

$$R_E = \frac{V}{E} \quad V\ W^{-1}\ cm^2 \tag{6-8a}$$

or

$$R_{E_\lambda} = \frac{V_\lambda}{E_\lambda} \quad V\ W^{-1}\ cm^2 \tag{6-8b}$$

where

V = sensor output in volts and

E = incident radiant areance in W cm^{-2}.

It is important to be certain that an experiment is configured so that the instrument is operating in its linear range.

Calibration Configurations

Basic requirements for the calibration of any radiometric instrument are the availability of one or more accurately known sources of radiation and the

positioning of such sources with respect to the instrument so that the geometry of the incident beam of radiation is clearly defined.* There are several possible configurations, each with advantages and disadvantages. The primary concern is the geometry of the radiation beam.

Distant Small-Source Configuration. A small calibration source of radiant pointance, I, is placed at a great distance, S, (see figure 6-3) so that the image of the distant source falls entirely within the field stop of the instrument. In terms of rays, every source ray that passes through the aperture or entrance pupil of the instrument also passes through the field stop. The incident radiant areance or irradiance responsivity can then be computed directly from the following relationships:

$$R_E = V/E = VS^2/I \tag{6-9}$$

This configuration is necessary for calibration of a point source radiometer.

Distant Extended-Source Configuration. A large calibration source of uniform, isotropic radiant sterance, L,† is placed at a distance but still close enough to the instrument so that its image completely fills the field stop (see figure 6-4). In terms of rays, a ray from any point in the field stop passing through any point in the aperture or entrance pupil arrives at the calibration source. In this case, it is the radiant sterance responsivity which can be computed directly from the relation $R_L = V/L$. This is true because, neglecting transmission losses, the radiant sterance has the same value at the source and the instrument aperture.

This method is used for calibration of spatial radiometers which are used for measurements of extended targets. Thus, the spatial variation of radiant sterance over targets such as ships, tanks, cars, buildings, airfields, and terrain can be determined best with instruments calibrated in this manner. An especially desirable practice is the location of extended calibration sources alongside the targets to be measured. Then the atmospheric path is the same for target and calibration source radiation.

Near Extended-Source Configuration. A large isotropic extended source is placed directly in front of the instrument aperture where it completely fills

---

*This permits accurate evaluation of the incident radiant quantity (radiant sterance radiance, incident radiant areance, or radiant flux).

†Isotropic radiance must be constant over the full solid angle subtended at every point of the source by the entrance pupil or receiving aperture of the radiometer.

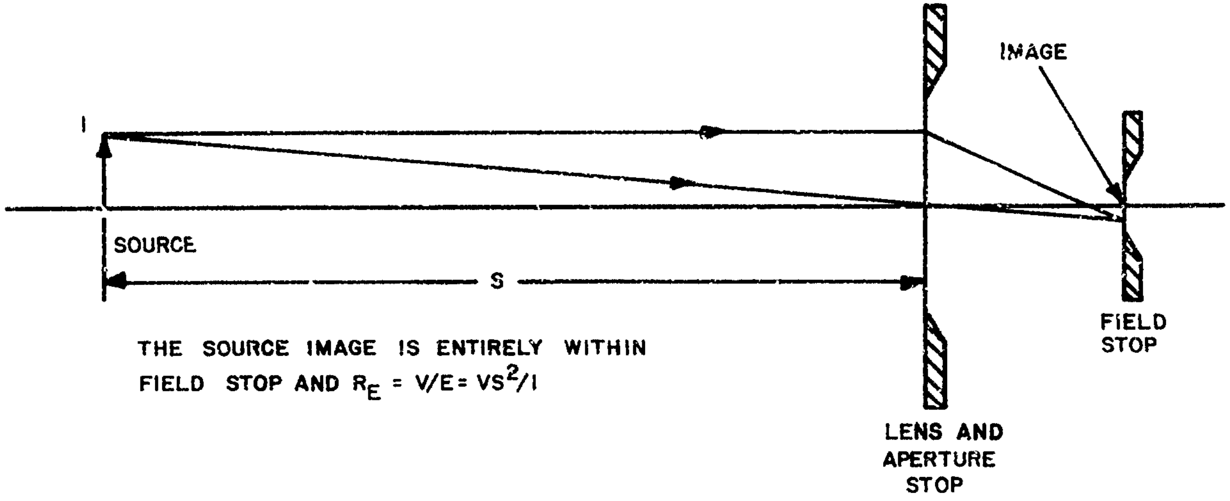
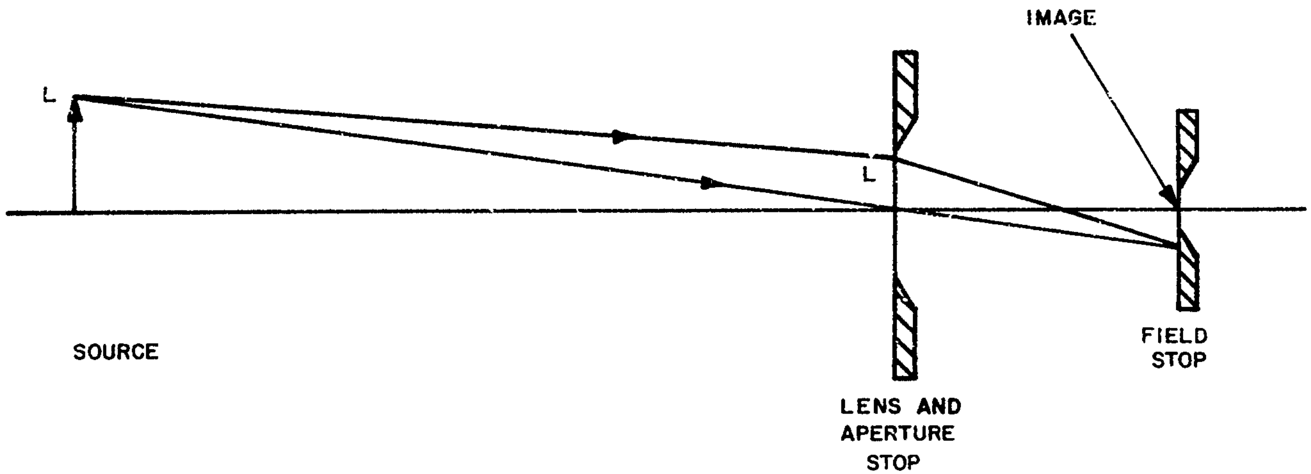


Figure 6-3. Distant small-source configuration.



THE SOURCE IMAGE COMPLETELY FILLS THE FIELD STOP AND $R_L = V/L$

Figure 6-4. Distant extended-source configuration.

the aperture and field with radiation of uniform radiant sterance, L (see figure 6-5). The radiant sterance or radiance responsivity, R_L, is then computed directly. As shown in figure 6-5, the source is not imaged at the field stop in this method. The radiometer should be focused exactly as it would be during the measurements of unknown source radiation.

The source completely fills both the aperture and the field, but the image of the source is not at the field stop. Note that the rays which meet at the field stop are not parallel as they leave the source, $R_L = V/L$.

The near small-source method will not be discussed here since it is not often used. Discussions of this method are given in many references.

Use of a Collimator. The distant source methods can be employed without actually placing the sources at great distances by placing them at the focus of a collimator. The radiometer to be calibrated is positioned in the collimated beam, which then appears to be coming from a source at infinity. This has the advantage of keeping all the components involved in the calibration conveniently accessible for manipulation and control. In addition, it makes it possible, in real situations, to control background radiation more easily and eliminate the effects of atmospheric attenuation by placing the source, collimator, and radiometer in an enclosure that can be flushed with dry nitrogen.

Linearity Calibration. Calibration measurements must be made over a wide range of incident radiant areance values (certainly including the range over which measurements will be made) in order to establish a linear calibration. It is essential to measure down to the noise level as well as up to saturation.

Incident radiant areance can be varied in the following ways:

- Increase temperature (disadvantage--also changes spectral distribution of energy).

- Vary aperture size using collimator.

- Employ neutral density filters (disadvantage--needs to be calibrated and may modify the system response).

- Vary source distance (disadvantage--increase in atmospheric path).

When varying source size and distance, the image size relative to the chopper wheel openings must be considered. The chopper acts as a spatial filter; as the image size approaches the size of a wheel opening, the output signal will be distorted. This effect is illustrated by the plot of figure 6-6.

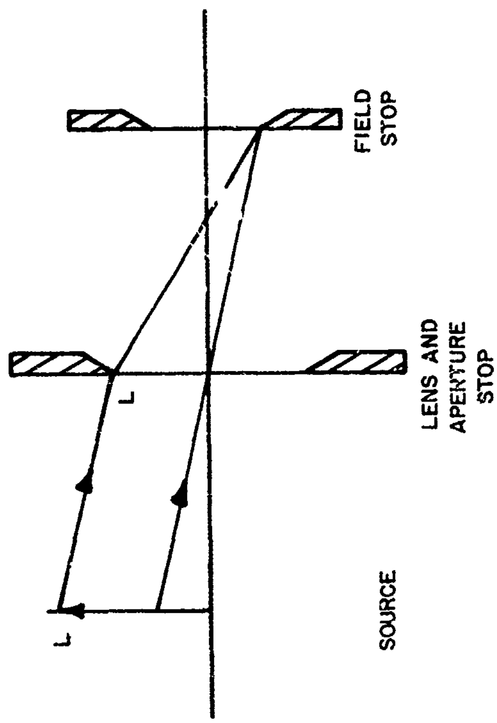


Figure 6-5. Near extended-source configuration.

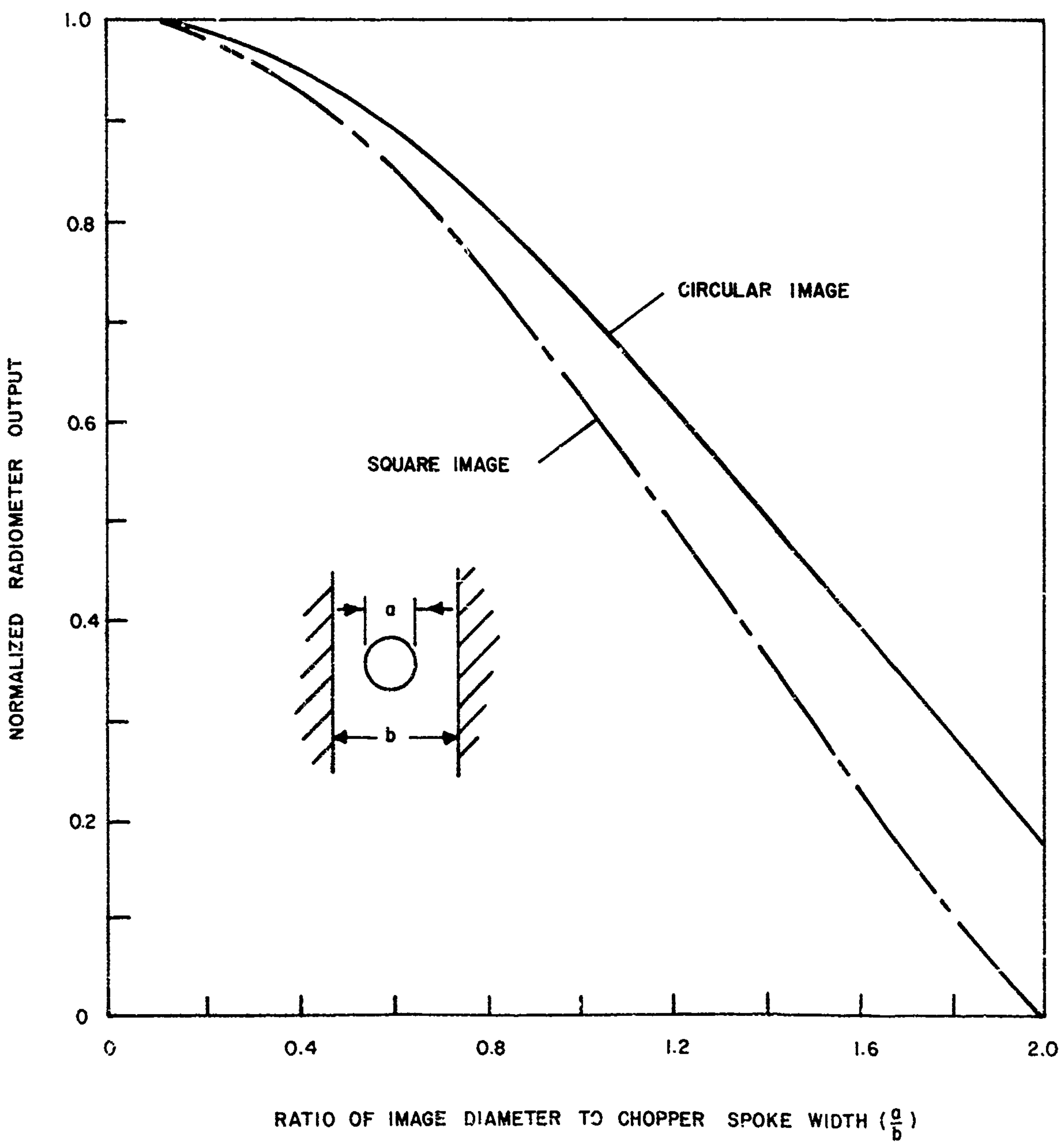


Figure 6-6. Effect of image size on radiometer output.

The source distance of the distant small-source method can be varied up to a point where the inverse-square relationship to the radiant flux no longer holds. A common working rule is to use distances greater than twenty times the largest dimension of the source or receiver aperture.

Spectral Response Calibration. The spectral response (not to be confused with responsivity) of a radiometer can be determined by computation using spectral response data on each component measurement of the entire system. The first method is strongly discouraged because of numerous pitfalls. It is always preferred to measure the entire system in a nitrogen environment using a collimated output from a spectrally pure, monochromatic source (double monochromator). The recommended technique is to measure the spectral incident radiant areance over the wavelength region to which the instrument detector is sensitive, with a "black" detector having a constant spectral response (accuracy of measurement depends upon this fact). The spectral response, $R'(\lambda)$, of the instrument is equal to the ratio of the instrument detector output to the output of the black detector or

$$R'(\lambda) = \frac{V_I(\lambda)}{V_{BD}(\lambda)} \tag{6-10}$$

where

V_I = voltage from instrument and

V_{BD} = voltage from black detector.

The special response is usually normalized by a technique as described in the "normalization" section. If a constant monochromatic radiant flux output is available, the spectral response is measured directly from the instrument output.

FOV Mapping. The FOV of the instrument can be mapped using a small source of constant radiant pointance either at significant distance or at the focal point of a collimator. The image on the detector should be in focus and small in size. The source is either moved horizontally and vertically or the instrument is scanned across the source. Data points are taken at increments in order to obtain the desired resolution. The data points are peak normalized and plotted in a matrix to define the FOV uniformity.

Temporal Response Calibration. The temporal or frequency response characteristics of the instrument must be known, particularly if measuring rapidly modulated sources. The instrument should be calibrated using a source

which can be modulated over the range of frequencies to be measured. The amplitude of the output signal is then measured as a function of the modulated input radiation. The output signal will include effects due to the detector, amplifiers, and any other electronic components in the instrumentation.

Calibration Problems

Background Sources. The distinction between a target source and a background source of radiation is an arbitrary one that depends only upon the interest of those making a measurement, and is not an inherent property of the source. In calibration, any radiation that enters an instrument along with the radiation from the desired source and which, hence, can cause an additional output response not correctly attributable to the source of interest is classed as background radiation.

Background sources must always be considered in a calibration. Radiation may come directly from a source within the sensor FOV or may be scattered into the sensor due to poor optical design. Since calibrations are generally performed under fairly well controlled conditions, it is usually possible to eliminate most of the serious background sources. A very difficult background condition is for the case of calibrating a long wavelength ($8\mu m$ to $14\mu m$) sensor where everything at room temperature becomes a significant source. Techniques for this case would utilize extended blackbodies (filling the sensor FOV), or cooled shutters or baffles (these devices may have reflections).

If a modulated source is to be used for a calibration source, the chopper should be placed between a constant-temperature baffle containing the source aperture and the blackbody. In this manner, all rays from the blackbody will be modulated before reaching the sensor. The sensor will then alternately "see" the blackbody defined by the aperture and the chopper blade.

Atmospheric Attenuation. The attenuation of ir radiation by the atmosphere is a highly variable function of wavelength and of meteorological parameters (particularly, the concentration of water vapor), which are themselves highly variable. In general, when a radiometric instrument is calibrated in terms of the incident radiometric quantity at its receiving aperture (entrance pupil), the possibility that there is appreciable attenuation in the optical path between a calibration source and the instrument should always be considered. Detailed computations of the amount of this attenuation should be carried out whenever it appears that it may be significant in relation to the desired accuracy of the calibration.

Ideally, all calibrations should be carried out in a nitrogen purged environment. This is especially necessary for initial calibrations of a new instrument. The collimated source calibration method is probably the most amenable to nitrogen purging. Once the instrument is well characterized, calibrations can be compared in wavelength regions of little or no atmospheric attenuation.

CALIBRATION MATHEMATICS

Basic Equations

Most of the essential radiant flux equations were covered in the "RADIATION AND RADIOMETRY" and the "CALIBRATION TECHNIQUES" sections of this chapter. A few additional equations are useful to specify the geometrical distribution of flux. The distribution of radiant sterance (see figure 6-7) is defined as:

$$L = d^2\phi/(d\omega \cos\ \theta\ dA_s) \tag{6-11}$$

where

$d\phi$ = radiant flux,

dA_s = area of radiating source, and

$d\omega$ = solid angle.

Note: The cos θ term converts area or solid angle into projected quantities.

The entire theory of radiation geometry can be deduced from equation 6-11. The total flux radiated from a surface, A_s, is

$$\phi = L \int_{A_s} dA_s \int_{\omega_s} \cos\ \theta\ d\omega_s = L\ A_s\ \Omega_s \tag{6-12}$$

where

Ω_s = projected solid angle.

The radiant pointance of the source is defined by the following equation:

$$I = \lim_{\Delta\omega\to 0} \Delta\phi/\Delta\omega = \int L \cos\ \theta\ dA_s. \tag{6-13}$$

(Valid only in the limit as $\Delta\omega$ approaches 0 or distance to the source is very large relative to the source area.)

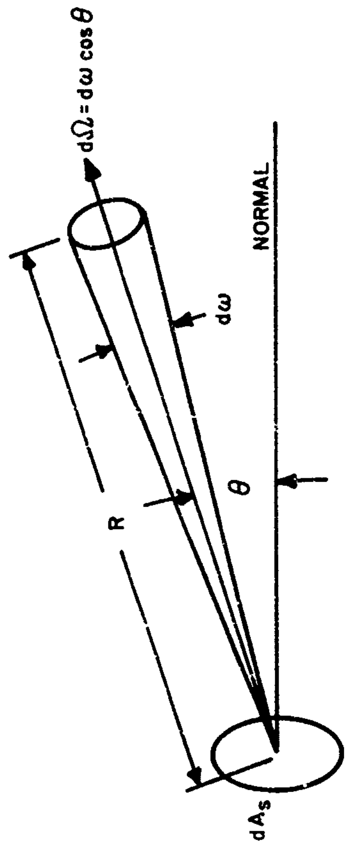


Figure 6-7. Radiation geometry.

When the distance, R, between the source and receiver is large (R must usually be 10 to 20 times maximum dimension of receiver or source aperture for 1% accuracy in this approximation), the incident radiant areance is given as

$$E = \frac{d\phi}{dA_s} = I \frac{d\Omega_s}{dA_s} = \frac{I}{R^2} . \tag{6-14}$$

The exitent radiant areance (radiant exitance), M, for a Lambertian source radiating into a hemisphere (the case for the typical blackbody simulator) is

$$M = \pi L \ W m^{-2} . \tag{6-15}$$

Some useful relationships for spectral calibrations define the concept of wavenumber, $\bar{\nu}$ as

$$\bar{\upsilon} = \frac{1}{\lambda} = \frac{\nu}{c} \tag{6-16}$$

where

υ = optical frequency and

c = speed of light.

The relationship between spectral resolution of a spectrometer in wave numbers or wavelength is

$$\Delta \bar{\nu} = - \frac{1}{\lambda^2} \Delta \lambda. \tag{6-17}$$

Normalization

One of the most important mathematical considerations in calibration is normalization. Quantities such as the spectral response of a radiometer as a function of wavelength are typically treated in a relative rather than an absolute manner. This requires a normalization process which is usually the technique called peak normalization. The peak normalized spectral response of a bandpass radiometer is

$$R'_{np} (\lambda) = \frac{R'(\lambda)}{R'(\lambda)_{max}} . \tag{6-18}$$

The "effective" incident radiant areance, E_{EFF}, available in the bandpass of this radiometer at a distance, R, from a blackbody simulator (or in the beam of a collimator of focal length, R) is

$$E_{EFF} = \frac{A_s}{R^2} \int_0^{\infty} R'_{np}(\lambda) L_{BB}(\lambda) d\lambda \qquad (6\text{-}19)$$

where

A_s = source area,

R = distance to source, and

L_{BB} = radiant sterance from blackbody at temperature T.

The value E_{EFF} is then used in the incident radiant areance responsivity calibration (equation 6-8) or

$$R_E = V/E_{EFF}.$$

The responsivity, R_E, is then used to determine unknown incident radiant areance by measuring the instrument output and dividing that output by R_E.

The peak normalized method is usually recommended for spectral responses similar to A in figure 6-8. An irregular system response such as B in figure 6-8 may call for normalization to the average. An arbitrary normalization technique would be required for case C in figure 6-8. In this case, the spike contributes very little to the overall response to the radiation. Obviously, it is very important to explain the type of normalization used.

Another aspect which must be considered in the normalization problem is that of the result when the instrument spectral response is multiplied with the spectral distribution of the radiation to be measured. Sources with line emissions or abrupt changes in radiation emitted near the ends of the instrument's spectral response may have an impact upon the normalization used. This is illustrated in figure 6-9.

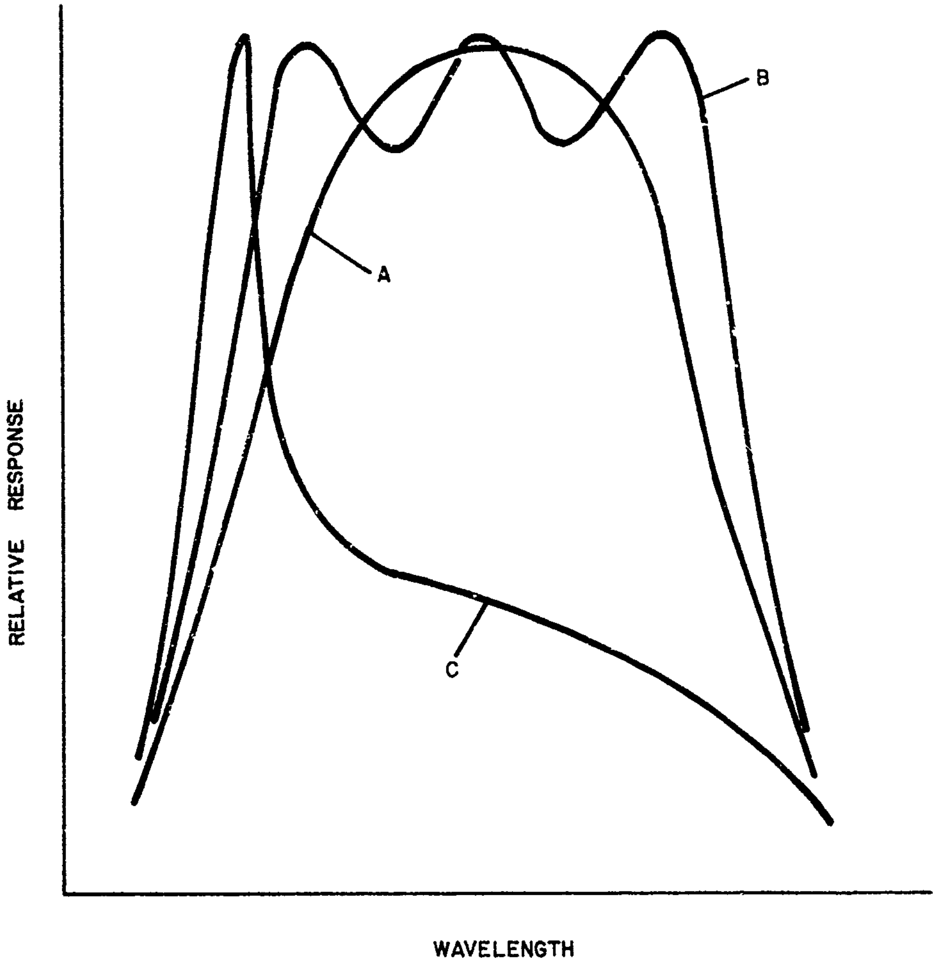


Figure 6-8. Examples of radiometer spectral response.

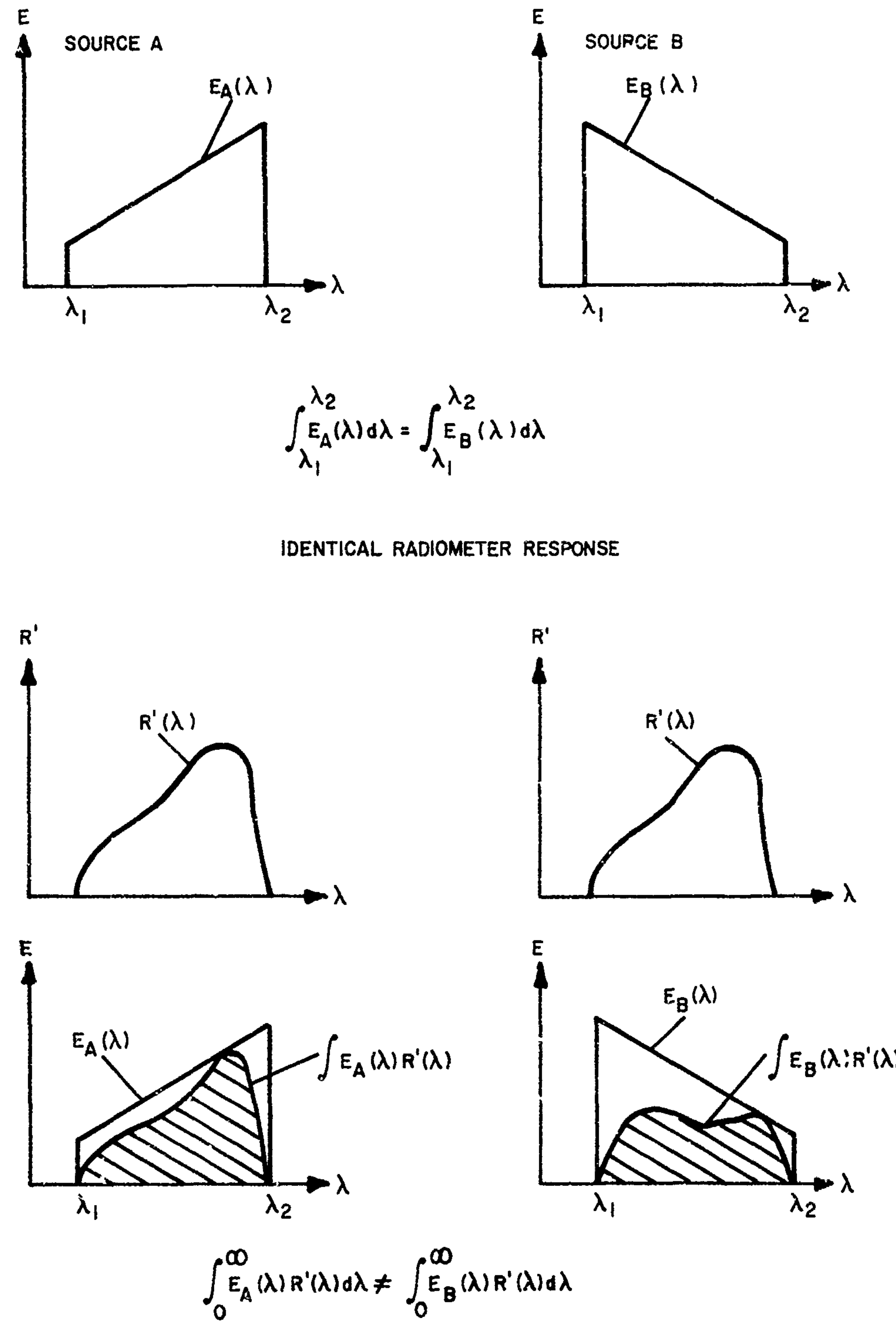


Figure 6-9. Effect of radiant spectral distribution convolved with radiometer response.

Discussion of Errors

Calibration errors may be examined by considering all of the terms affecting the determination of instrument responsivity. The equation for R_E is

$$R_E = \frac{\pi V_c \; R_c{}^2}{\varepsilon_c \, \sigma T_c{}^4 A_c R'(\lambda) \, \tau_{ac} \, \rho_m} \tag{6-20}$$

where

ε_c = emissivity of calibration source,

σ = Stefan-Boltzmann constant,

T_c = calibration source temperature,

A_c = calibration source aperture,

$R'(\lambda)$ = radiometer weighted system response to radiation,

V_c = calibration voltage,

R_c = calibration source distance (focal length for a collimated source),

τ_{ac} = atmospheric transmission over calibration path, and

ρ_m = reflectance of mirror (if collimator is used).

The uncertainty (excluding recording, data reduction and human errors) can be expressed as (assuming parameter independence and normality):

$$\left(\frac{\Delta R_E}{R_E}\right)_{RMS} = \left[\left(\frac{\Delta\varepsilon_c}{\varepsilon_c}\right)^2 + \left(\frac{4\Delta T_c}{T_c}\right)^2 + \left(\frac{\Delta A_c}{A_c}\right)^2 + \left(\frac{\Delta R'(\lambda)}{R'(\lambda)}\right)^2 + \left(\frac{\Delta V_c}{V_c}\right)^2 + \left(\frac{\Delta R_c}{R_c}\right)^2 + \left(\frac{\Delta \tau_{ac}}{\tau_{ac}}\right)^2 + \left(\frac{\Delta \rho_m}{\rho_m}\right)^2\right]^{1/2} . \tag{6-21}$$

Examining on a term-by-term basis:

$\frac{\Delta\varepsilon_c}{\varepsilon_c}$ The emissivity of small cavity-type blackbody simulators is usually within 1% of unity. A large area blackbody simulator can have uncertainties greater than 5%.

$\frac{4\Delta T_c}{T_c}$ The source temperature uncertainty is quite important due to the factor of four which multiplies that error. A small cavity-type blackbody simulator with an internal reference thermocouple (with an accurate calibration) will typically have uncertainties less than 1%. A large area blackbody simulator is much more subject to temperature gradients and non-uniformities. Note: this parameter is also a function of $R'(\lambda)$.

$\frac{\Delta A_c}{A_c}$ The uncertainty in aperture area becomes larger as the aperture becomes small and difficult to measure. Small apertures are susceptible to dust particle contamination and diffraction effects if the size is of the order of the radiation wavelength. The uncertainty of well made apertures is usually less than 2%.

$\frac{\Delta R'(\lambda)}{R'(\lambda)}$ This factor, R', for the instrument system spectral response is multiplied with the spectral distribution of the source radiation to determine total radiation available to the instrument. This factor must be accurately measured to minimize uncertainty. Coincident regions of rapid rate of change of filter and source distributions are particularly critical in introducing uncertainties. This uncertainty in well behaved and carefully calibrated systems is probably within a few percent. This area can easily become a very large uncertainty if not treated carefully.

$\frac{\Delta V_c}{V_c}$ The calibrating signal voltage uncertainty is produced by instrument susceptibility to time and temperature dependent drifts, stray electromagnetic fields, or other variables in the instrument. Accurate characterization and experience with an instrument can quantify this uncertainty. The uncertainty of a measurement can be greatly influenced by the stability and repeatability of the instrument. This uncertainty hopefully would be less than a few percent.

$\frac{\Delta R_c}{R_c}$ The uncertainty in range to the calibration source should be less than 1% by careful measurement.

$\frac{\Delta\tau_{ac}}{\tau_{ac}}$ The uncertainty due to atmospheric transmission can be eliminated by purging the optical path with nitrogen. This is not too difficult with smaller collimators and is essential to minimize errors. It is difficult to estimate the atmospheric transmission over short paths, and it is significant in many wavelength regions. The transmission in the water vapor region, particularly, will vary day-to-day over the same path length.

$\frac{\Delta\rho_m}{\rho_m}$ The uncertainty in mirror reflectivity for the collimator calibration is subject to the condition of the mirror surface. The uncertainty for a particular type of mirror coating is probably within a few percent for most calibrations. A more significant uncertainty may be due to collimator output beam uniformity. This uniformity should be measured and accounted for as necessary.

A sample calculation for a good, stable, carefully calibrated instrument could be

$$\left(\frac{\Delta R_E}{R_E}\right)_{RMS} = \Big[(0.01)^2 + (0.04)^2 + (0.02)^2 + (0.02)^2 + (0.02)^2$$

$$+ (0.01)^2 + (0.02)^2 + (0.02)^2\Big]^{1/2}$$

$$= 0.062 \text{ or } 6.2\%$$

This would represent an excellent case. The uncertainty in the terms for instrument spectral response, signal voltage variability and atmospheric transmission are easily greater than those shown. A more typical total uncertainty could be near 10%.

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CHAPTER 7

MEASUREMENT METHODOLOGY

Grover S. Amick

INTRODUCTION

This document presents, by means of simplified block diagrams and flow diagrams, a general procedure that can be used as a guide for some types of ir measurement programs. The purpose is not to present a precise or rigid treatment for a specific type of program; rather, an attempt is made to provide sufficient detail to permit individual test directors to expand and define the general areas in a way that will facilitate the establishment of a coherent, repeatable, and documented measurement methodology procedure for their specific equipments and applications. The establishment of a specific measurement methodology procedure, amply documented, within each facility is strongly recommended.

This document should also be of benefit to project engineers who procure or specify ir measurements. For these individuals, it is hoped that the block diagram format will illuminate the rationale for those sometimes seemingly unnecessary efforts that are only indirectly concerned with the desired data but directly support the acquisition and reporting of high-quality ir measurement data.

DISCUSSION

The term "measurement methodology" implies procedures that are used to transform measured data into a usable report format. Consequently, it is a generalization of the classical ideas of data reduction. It encompasses the areas of equipment assembly, checkout, and calibration; test conduct and data acquisition; data assessment; and reporting. Much planning is required to prepare a reasonable measurement methodology. This is made easier if some knowledge of the results to be expected from the test is available.

Pretest Data Survey

One frequently neglected part of the planning for any measurement program is the failure to conduct a pretest data survey. The **a priori** knowledge of the ir signature values anticipated during the various phases of the measurement program is of tremendous value in preparing the test plan. The target size and intensity values, used in conjunction with the instrument sensitivity/spatial restrictions, will generally provide the bounds for the flight profiles to be used. By using these realistic bounds, an optimum test plan can be generated that will ensure that an appropriate, measurable signal will be available to the instrument. (See figure 7-1.)

The pretest data survey can provide a baseline "expected value," which can be used during the data acquisition and reduction process to ensure that the data emerging from the test program are yielding reasonable values.

For all targets used for ir measurements, there exist some means for determining an approximate ir signature value. In some cases, very precise data for some similar flight regimes on the same target may be found in prior ir measurements. In addition, there are measurement programs that have been conducted on similar targets. If actual measurement data are not available, calculated values from available ir computer models may be used.

Alternative methods for estimating ir signature values include the use of simplified geometric models. For example, the temperature area relationship may be computed for the hot metal radiators and, in some cases, for the plume. These simplified calculations will provide some degree of guidance and are worth the preparation in light of the potential advantages. Another method is to estimate the ir signature based on the engine type, the number of engines, and the engine operating parameters. Combining this information with measurements of an **equivalent** engine type in a test stand, a **rough** estimate of the test aircraft's ir-signature for the desired engine operating conditions may be obtained.

If the test article has some prior measurement data or model data for specific flight conditions, every attempt should be made in the project planning stage to include some of those specific conditions during the test series. If some overlapping test conditions are included, post-data correlation techniques may be used for data comparisons.

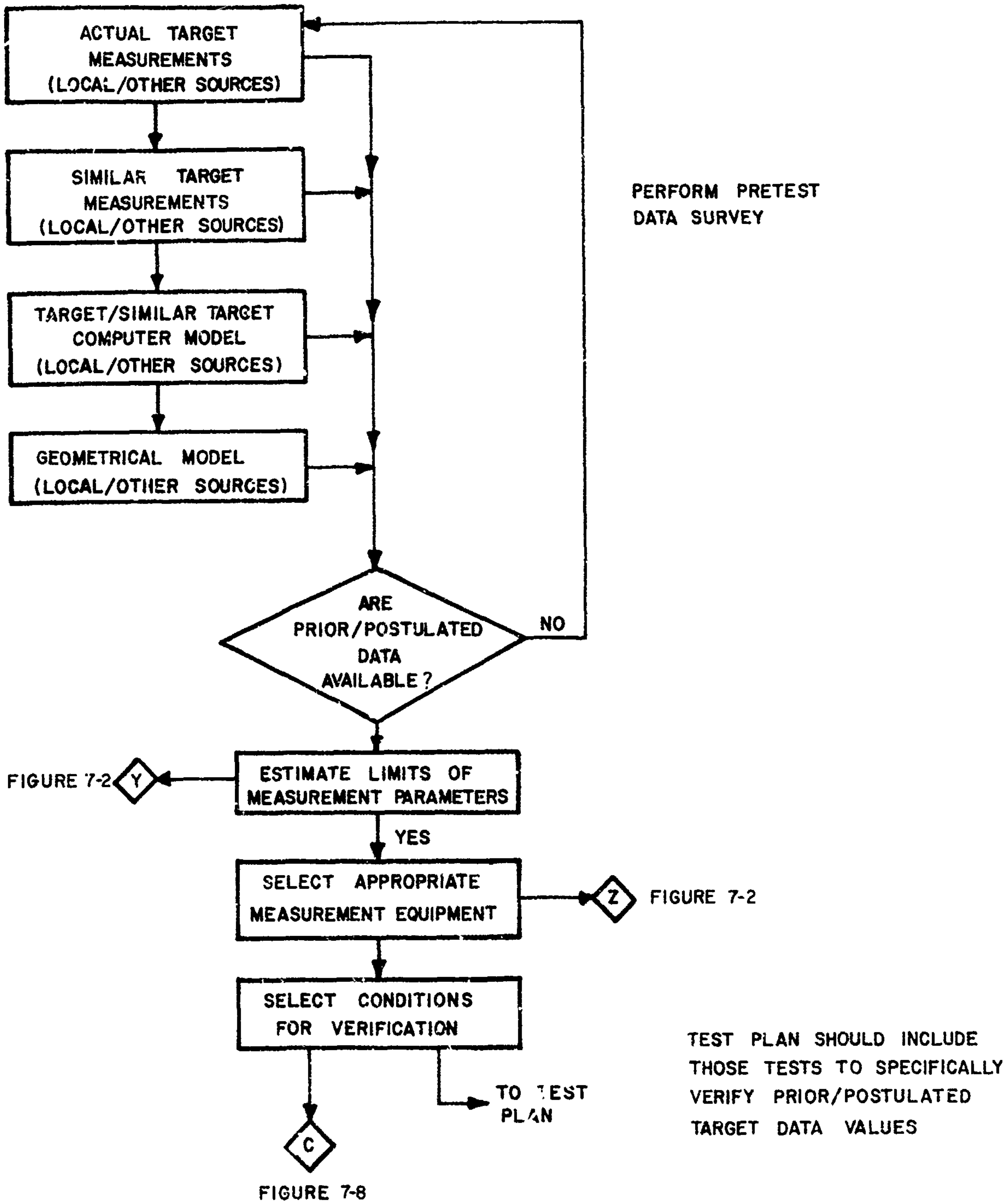


Figure 7-1. Pretest data survey.

Pretest Equipment Checkout

This initial test phase of an ir measurement program usually starts with assembling the various equipments that will be used in the program. The equipments might be radiometers, spectrometers, interferometers, seeker radiometers, ir seekers, etc. In addition to the actual sensor assembly unit used, it will generally be necessary to use consoles, power supplies, and other equipments to complete the instrumentation suite being readied. As shown in figure 7-2, the first step is to define the specific equipments that will be used in the test series. The type of instrument used is not a sufficient description; the definition should include all pertinent equipment characteristics as well as the actual item-peculiar nomenclature (such as serial numbers).

The next step is to define the interconnections used to combine these equipments into a measurement-instrument configuration. If the interconnections are adequately described, the test setup can be accurately repeated if desired. This repeatability in the equipment setup is necessary to ensure that the field site unit will operate exactly as it did at the pretest laboratory site. It is also of potential value in field-level troubleshooting and ensures that the post-test laboratory setup conforms in all respects. These interconnection descriptions can provide the records for future test programs to ensure commonality in measurement techniques.

After the pretest equipment setup is complete, the next logical step is to determine the equipment calibration status. There may be cases in which the equipments have been used recently in the same capacity and sufficient recent calibration data are available. However, in most cases, an equipment calibration cycle must be conducted.

The actual calibrations performed depend largely on the type of instrument in use. For specific calibrations of equipments, refer to chapter 6 for the detailed description of procedures. There are several general types of calibration that can be treated here as procedural illustrations; they include the optical characteristics of the total system. When we speak of the total system, we include all lenses, choppers, and windows that will be used for each specific instrumentation suite.

An example is an aircraft installation in which the same instrument looks through different optical windows for different aspect-angle coverages. For this case, separate calibrations have to be performed for each configuration. It may be determined following the calibration that the use of different windows did not modify, say, the spectral response. The point to be emphasized is that the spectral response must be checked and verified through actual laboratory calibration rather than assumed to be a negligible function. Recall that it is not sufficient to multiply several average transmission coefficients over a finite spectral band. Transmission coefficients can be combined only when treated as a spectral transmission function with a truly

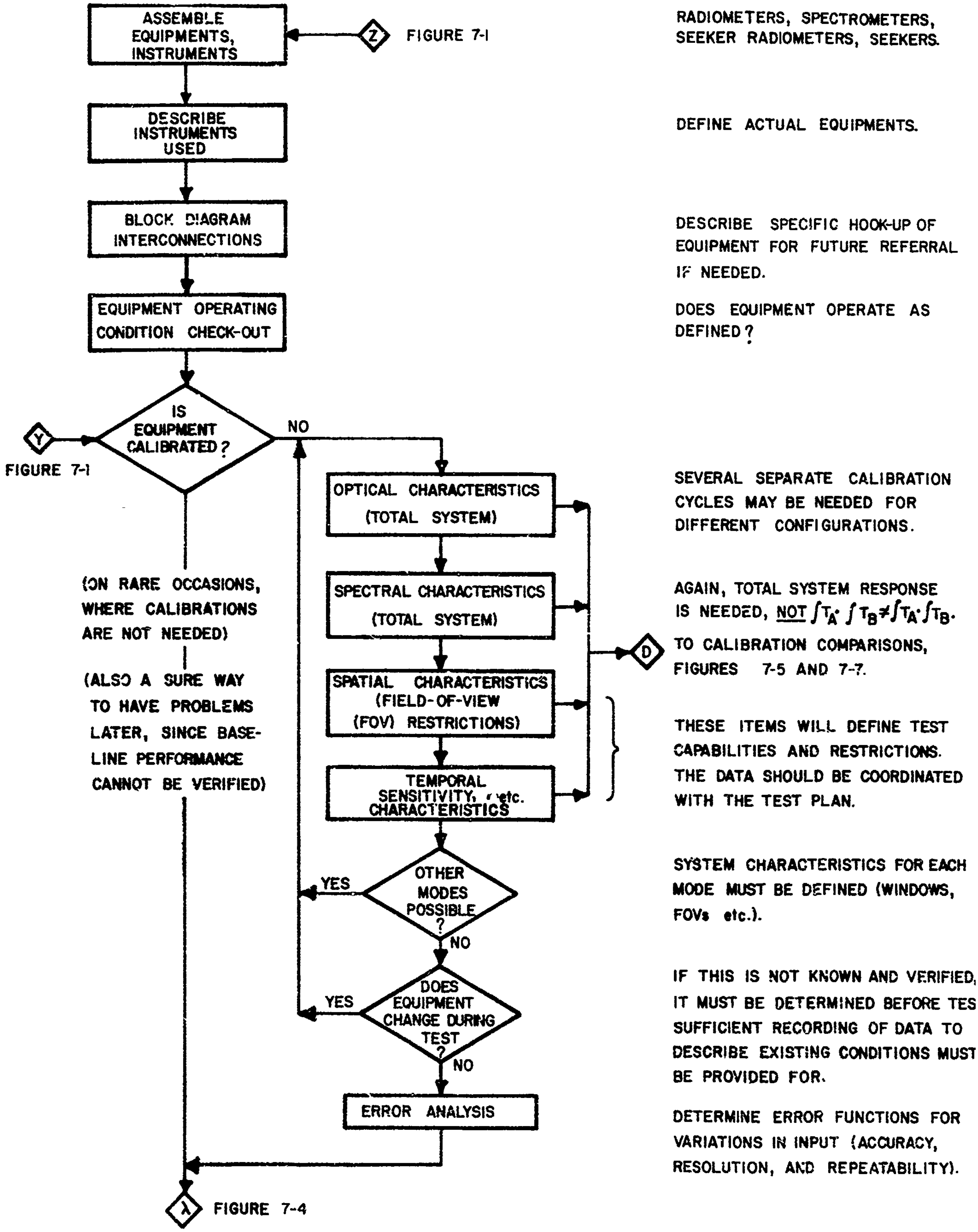


Figure 7-2. Pretest equipment checkout (laboratory).

negligible spectral bandwidth ($\Delta\lambda$). In many cases, it is generally more efficient to combine the optical elements and to perform the precise calibration rather than to rely on simplifying assumptions. Note here that if the optical quantities change because of window look angles, these look angles must also be calibrated.

The calibration results should then be compared with previous calibrations conducted on the equipment. To facilitate such comparisons, a calibration log should be established. This log will permit long-term trends to be identified and will indicate any nonconforming calibrations that occur. These calibration anomalies can be investigated prior to a test, and if sufficient cause for the anomaly is not found, an equipment change or repair can be made at that point.

After the spectral calibration has been satisfactorily performed, a spatial calibration should be conducted. The spatial characteristics will define the test capabilities and restrictions in terms of usable target to instrument slant ranges, and they should be coordinated with the test plan. This should ensure that satisfactory spatial responses will be obtained from the instrument during all phases of the test program. That is, that the target aircraft (or source being measured) is within the geometric limits of the instantaneous FOV and is not being inadvertently modified by the FOV characteristics. FOV uniformity and spatial modulation effects are two examples of sensitive parameters that must be calibrated during this effort.

The instrumentation suite's sensitivity characteristics should also be determined during this phase of the program. These parameters define the system characteristics available for the test program and can be useful in determining that a measurable signal can be obtained during the test. Test plans should be examined in coordination with the spatial and sensitivity characteristics and restrictions.

Additional modes of equipment operation should be reviewed. Gain changes, linearities, and gyro spin-ups are examples of the types of modes that should be considered and, if necessary, checked and calibrated. Completeness in checkout of all equipment during a laboratory pretest configuration will tend to minimize problems encountered during or after a measurement program. System time functions such as warm-up time, drift, variations with time, temperatures, or other dependent functions which affect system performance should also be identified and described.

The results of this pretest checkout should be described, documented, dated, and deposited in a file that will be accessible after the test, during data reduction, and in the subsequent planning and conduct of test programs.

Support Equipment Checkout

The measurement program test plan will specify some of the supporting data that will be required, but will generally not define all ancillary

equipments that should be monitored during any given test program. Supporting data include all data not directly provided by the measurement instrumentation suite. These equipments can be ground or airborne and may include such items as thermometers, hygrometers, time generators, radars, theodolites, and pilot gauges. Not all equipment details will be available for some sites that are remote from the measurement facility (such as weather central reporting station), but an attempt should be made to assimilate as many data as possible for all support equipments used. (See figure 7-3.)

It is recommended that a support equipment log be initiated to define all special parameters associated with the support function. Since the log will serve future test programs as well, it should also include the specific methods of use and define how these support data will be used in the eventual data reduction process.

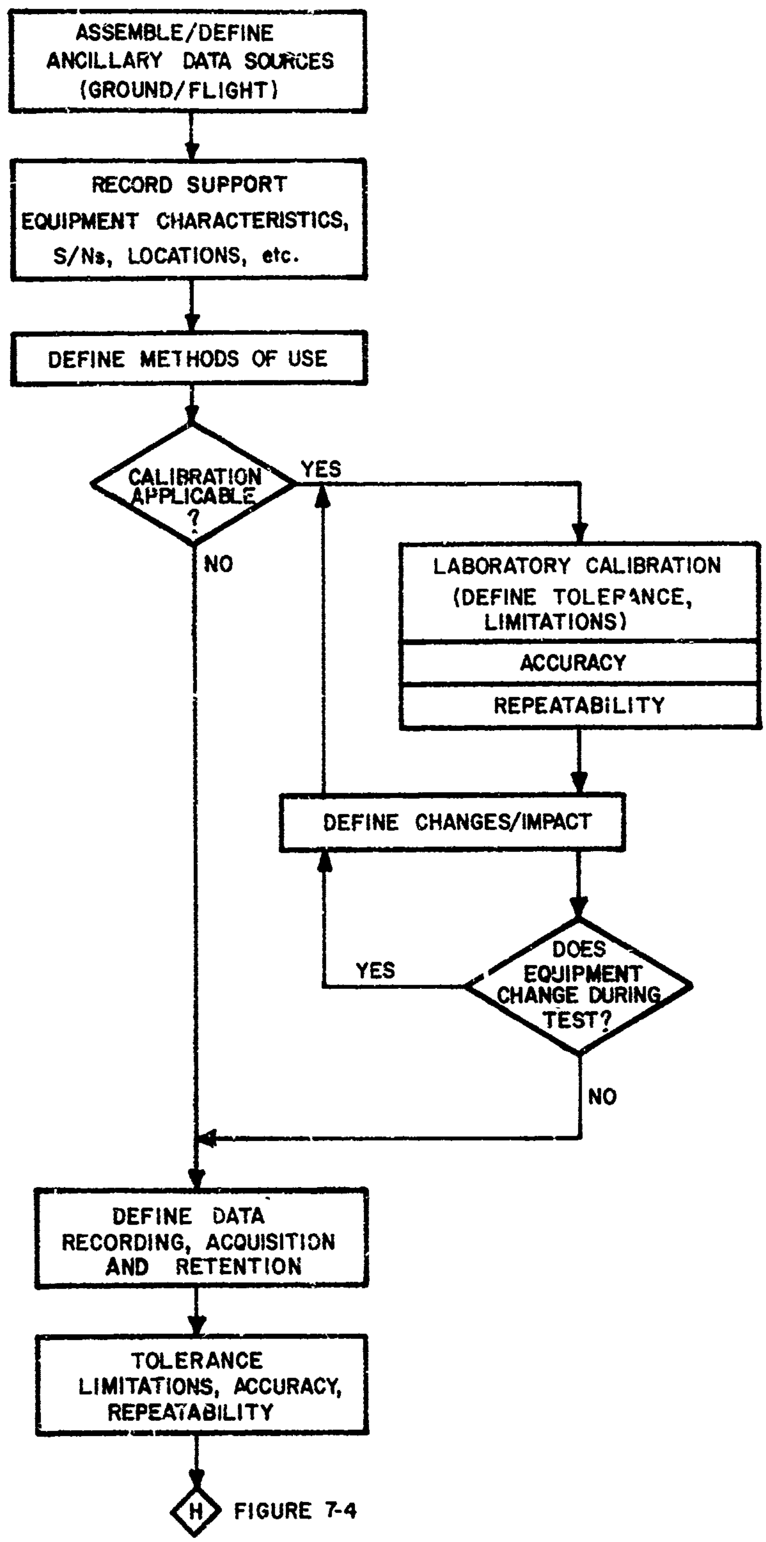
Once the support equipments have been identified, defined, and recorded, they should be examined to determine if calibration procedures are required. Where actual calibration is not required or is impractical, minimal data should include output-data accuracy, resolution, and repeatability. (For example, a pilot's airspeed indicator readable to the nearest 10-kn increment, with 10% accuracy and 20% repeatability; or a NIKE 'A' Site tracking radar with $\pm$ 2% slant-range accuracy, 0.1 μs data steps, $\pm$ 2° azimuth, $\pm$ 3° elevation, etc.).

Past experience has dictated that many of these data are readily available at test time but are historically difficult to acquire at some later date. Therefore, collection and recording of all pertinent data in a test program should be initiated as early as possible. A list of specific data requirements should be assembled and made available to the test conductor prior to the start of any test program.

For those equipments which lend themselves to the calibration cycle, pretest calibration should be conducted. Again, these data should be dated and placed in the project file to be available to all interested users.

In addition to the support equipments, the ir measurement equipment to be used in a test program should also be defined in the test program logbook.

At this state in the program, the total equipment structure should be examined in terms of critical components. Where loss of the support data will abort the measurement attempt, backup equipments might well be considered. For example, in most ground-to-air measurement programs, loss of the tracking-radar data will abort the data flight. Manning of an auxiliary site for this case might be economically justified if availability of the test article is very limited. The project sponsor, if made aware of these optional expenses, may authorize the extra cost needed to ensure satisfactory completion of the test program.



SOME EXAMPLES MIGHT BE RADARS, THERMOMETERS, HYGROMETERS, PILOT INSTRUMENTS, TIME GENERATORS, THEODOLITES.

NOT ALL EQUIPMENTS ARE COLLOCATED WITH TEST SITE INSTALLATIONS.

MAKE SURE SUPPORT EQUIPMENT IS IN TEST PLAN.

DATE ALL CALIBRATIONS AND OTHER TIME-SENSITIVE DATA.

FOR CRITICAL PARAMETERS, CONSIDER BACKUPS

PERFORM ERROR ANALYSIS.

Figure 7-3. Support equipment checkout.

Pretest Equipment Setup

The next step in the process is to set up the equipment at the test site. All equipment connections must be made, the instruments boresighted, and initial operational checks made for primary as well as critical backup equipments. After initial equipment operation has been verified, a field calibration procedure should be initiated. This procedure should be defined for the specific instruments in use but should be one that can be duplicated at the conclusion of the test series to verify consistent instrument operation. The field calibration results should be relatable to the pretest calibration data to verify that the equipment is operating identically with those equipments which were completely calibrated in the laboratory environment. Again, these data must be entered into a test record file to ensure that these data will be available for post-test data analysis. (See figure 7-4.)

Past test programs have demonstrated the advantages of using the instrumentation suite to measure a remote ir source. The remote ir source quite often provides the only means for comparing dissimilar equipments to verify data commonality. That is, the ir source can demonstrate the ability of the instrument to quantitatively measure a known source intensity. It is recommended that this baseline test be conducted as part of every ir measurement program. This ir source should be chosen to spectrally resemble the item under test to minimize any spectrally induced problems. Normally, the target will consist of both hot parts as well as spectral plume emissions. The instrument response to both of these types of signals should be understood prior to using these remote source simulations.

Test Conduct

It is at this point in the logical process that the actual measurement test series takes place. It should be adequately defined and described by a test plan that has been reviewed and approved by the test sponsor. (See chapter 5 on test plan preparation.)

Post-Test Data Acquisition and Assessment

The initial step in the data reduction process, which occurs after the test series has been completed, is to collect and assimilate all the data that have been obtained. Pilot debriefing papers and data sheets from all sources (on- and off-site locations) should be assembled and reviewed. (see figure 7-5.)

This review of the accumulated raw data permits an initial assessment of the ir measurement program. All elements of the test series, as well as the participating personnel, are available for timely discussions on the conduct of the test. At this point the problems encountered during the test series should be documented in sufficient detail to permit future programs to benefit

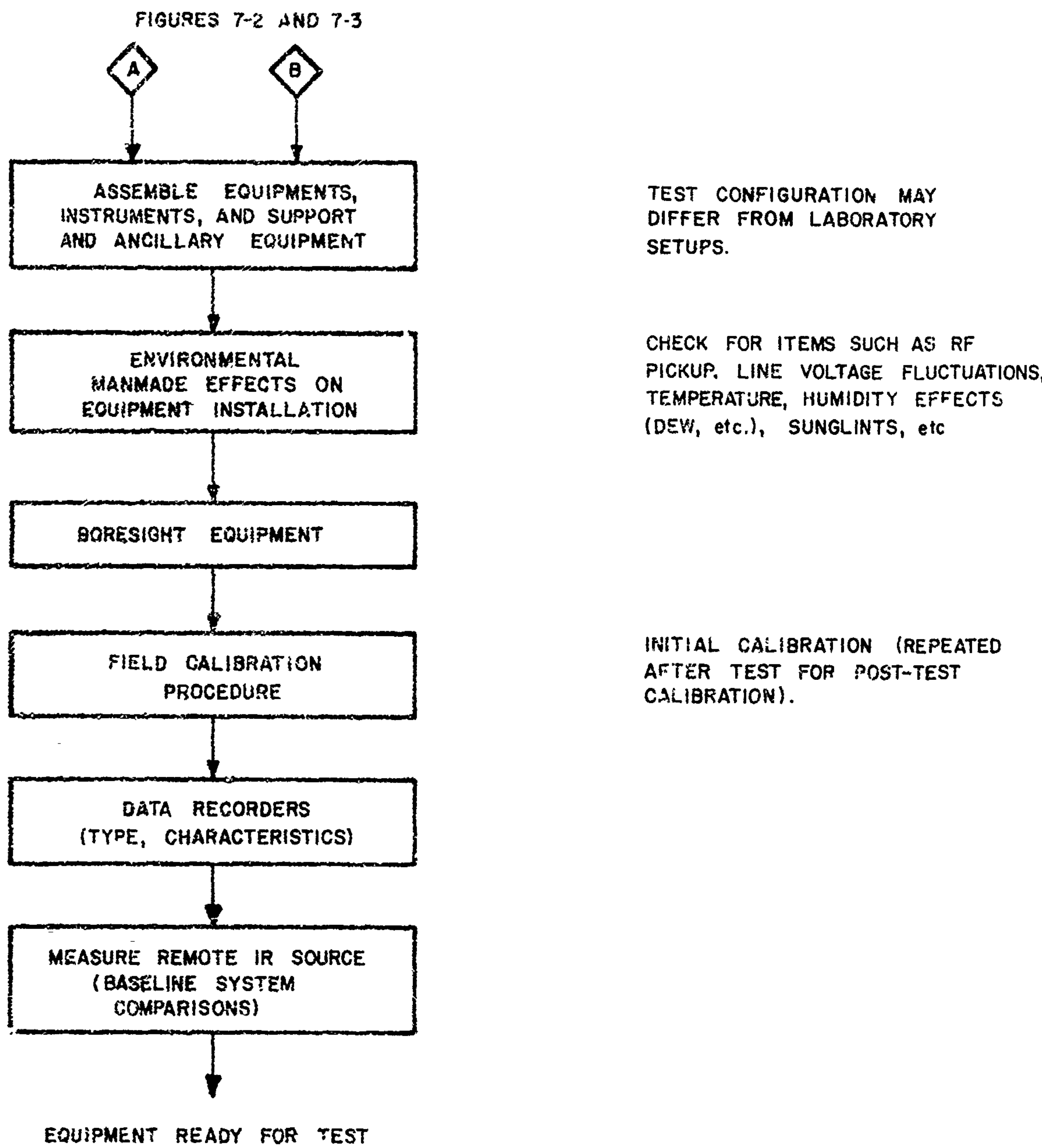
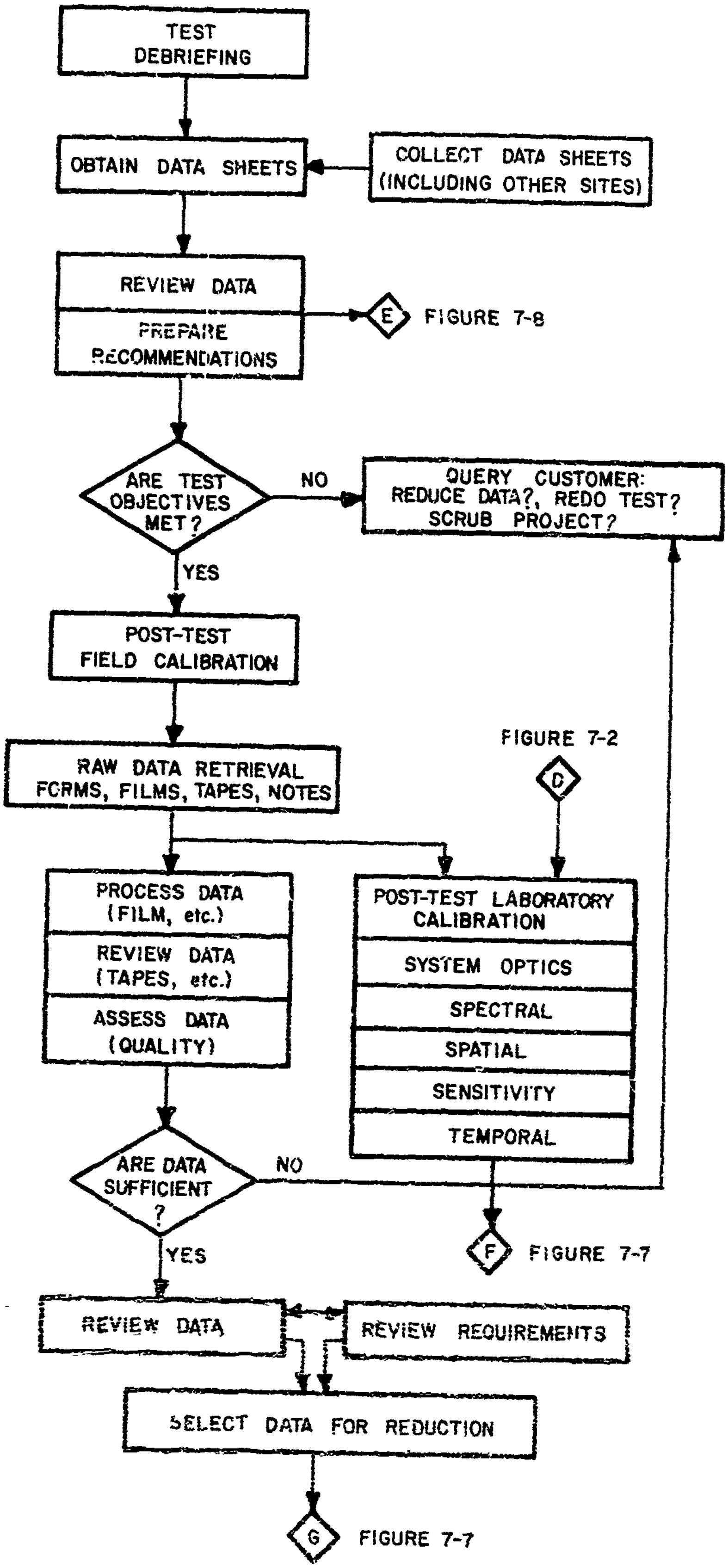


Figure 7-4. Pretest equipment setup.



MAKE NOTES FOR FUTURE TESTS.

RESOLVE ISSUES.

FOR FIXED SERIES OF VALUES, IF ANY SIGNIFICANT CHANGE IN VALUES IS NOTED, REDO ALL CALIBRATIONS DONE PER FIGURE 7-1 ATTEMPT TO RESOLVE ISSUES.

QUALITY OF DATA, ASPECT ANGLE COVERAGE, TARGET SPATIAL MODULATION (IMAGE SIZE), TRACKING QUALITY, SIGNAL/GAIN CONSISTENCY, VIDEO QUALITY, TIME ANNOTATIONS, COMPLETED DATA SHEETS.

VERY CRITICAL QUANTITATIVE STEP. DEFINES QUANTITY AND TYPES OF DATA THAT WILL BE FORMALLY REDUCED (DOLLARS, TIME IMPACT).

Figure 7-5. Post-test data acquisition and assessment.

from the experiences encountered. These data should be included in the project log and pertinent aspects extracted for inclusion in the final data report. The rationale for including the salient problem areas in the final report is to build up an accumulation of available knowlege to be shared by the total ir community--not to indicate deficiencies.

It is also at this point that a preliminary conclusion may be reached concerning whether the desired test objectives were met. For test programs in which only limited or marginal data were obtained, a prompt review with the task customer is recommended. Quite often, the cost of the detailed data reduction is greater than the data collection costs and it may thus be cost-effective to consider either redoing the test series or abandoning the project.

Coincident with the post-test review process, and before any equipment disassembly occurs, a post-test field calibration should be conducted. This calibration should be identical with the pretest field calibration described in the "Pretest Equipment Setup," section of this chapter. These post-test calibration results should be compared with the pretest calibration results and all anomalies resolved before the equipment is disassembled. The resolution of any anomalies at this point is crucial to the total program, for if any changes in equipment characteristics have occurred, there is a genuine question as to which calibration data are appropriate. In some instances, portions of the test program may have to be repeated to verify that the test data are valid. This is part of the rationale why calibrated source reference runs should be conducted periodically during the test sequence. This will aid in the determination of if and when a problem in the radiometer performance commenced.

Analysis of the raw data should provide an initial assessment of the quality and quantity of data that appear to have been obtained. This volume of data can be reviewed with respect to those data which are required, and a rationale can be developed for the data reduction procedures that should be employed.

Generally, the quantity of the raw data available for reduction will greatly exceed the requirements. One fairly common failing in a test program is to press on in a futile attempt to reduce and report all of the collected data. This approach often yields bulk amounts of data that are repetitive and descriptive only of the composite spread.

This process can be optimized, and the appropriate time to optimize is now--during post-test analysis and prior to data reduction. A technique that has been successfully used on at least one test series serves as an example.

An ir measurement program was conducted to evaluate the effectiveness of two prototype suppression systems. An aircraft, with and without suppressors installed, made repetitive flights past the measurement site. The instrument

in use was an interferometer that collected data at the rate of five frames per second. The total data accumulation for the three configurations for all duplicated flight profiles was considerable.

However, since the objective was to compare the effectiveness of the suppressor systems, specific points were developed by using the radar track data where multiple data points for all three situations were available. From the radar plots, the specific points for the individual data runs corresponding to the selected points and associated "range times" were recorded. Figure 7-6 illustrates the approach.

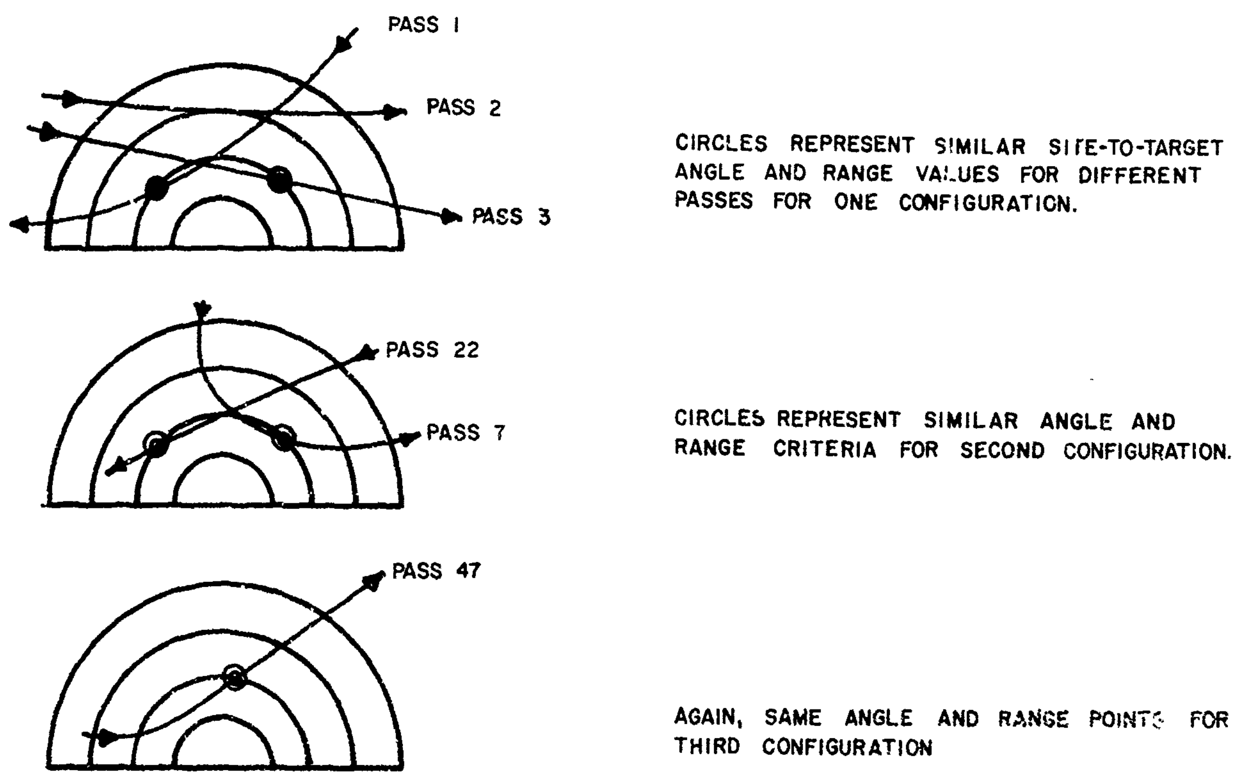


Figure 7-6. An approach to post-test analysis.

Therefore, the bulk of the data was limited to some finite time intervals during those specific runs for which the resultant systems could be compared in terms of suppression effectiveness.

Additional data review selected two "clean" rotating hover conditions for shape comparisons in the hover mode out of the seven rotating hover conditions measured. The unreduced data were placed in a data bank for future reference.

As a result, the large quantity of interferometric data available from the test series was reduced to manageable proportions for the eventual data reduction, correlation, and reporting.

This case serves as an example of what can be done; in most cases, the actual approach will differ. The point remains, however, that the data reduction process can be reduced to manageable proportions prior to the start of the data reduction process.

Data Reduction

From the previous section, we have selected the quantity and types of data that we desire to reduce to output data format. The next step is to select the data reduction procedures. In most cases, these data reduction procedures will have been previously established and, as such, should be already documented and described. These procedural descriptions should be assembled in anticipation of including them in the final report. Quite often, only a summary description will appear in the report text, with the salient procedural details relegated to an appendix. This information should be assembled into the project file at this time to document specifically the routine procedure used for the test series data reduction. (See figure 7-7.)

On occasion, in past programs, an obsolete routine has inadvertently been used while the updated routine has been assumed and thus routinely included in the output text. Inclusion of the specific data into the project file at this time will permit concrete establishment of the specific data programs actually used.

As the data reduction routine is employed, every effort should be made to provide as many cross-check points along the way as possible to ensure that errors which might occur do not go undetected. These cross-checks often will consist of parallel hand-calculated values to verify proper computer routines and input data values. Factors checked should include scale factors, optical quantities, calibration factors, range, unit conversions (feet to centimeters, etc.), and other conversion factors.

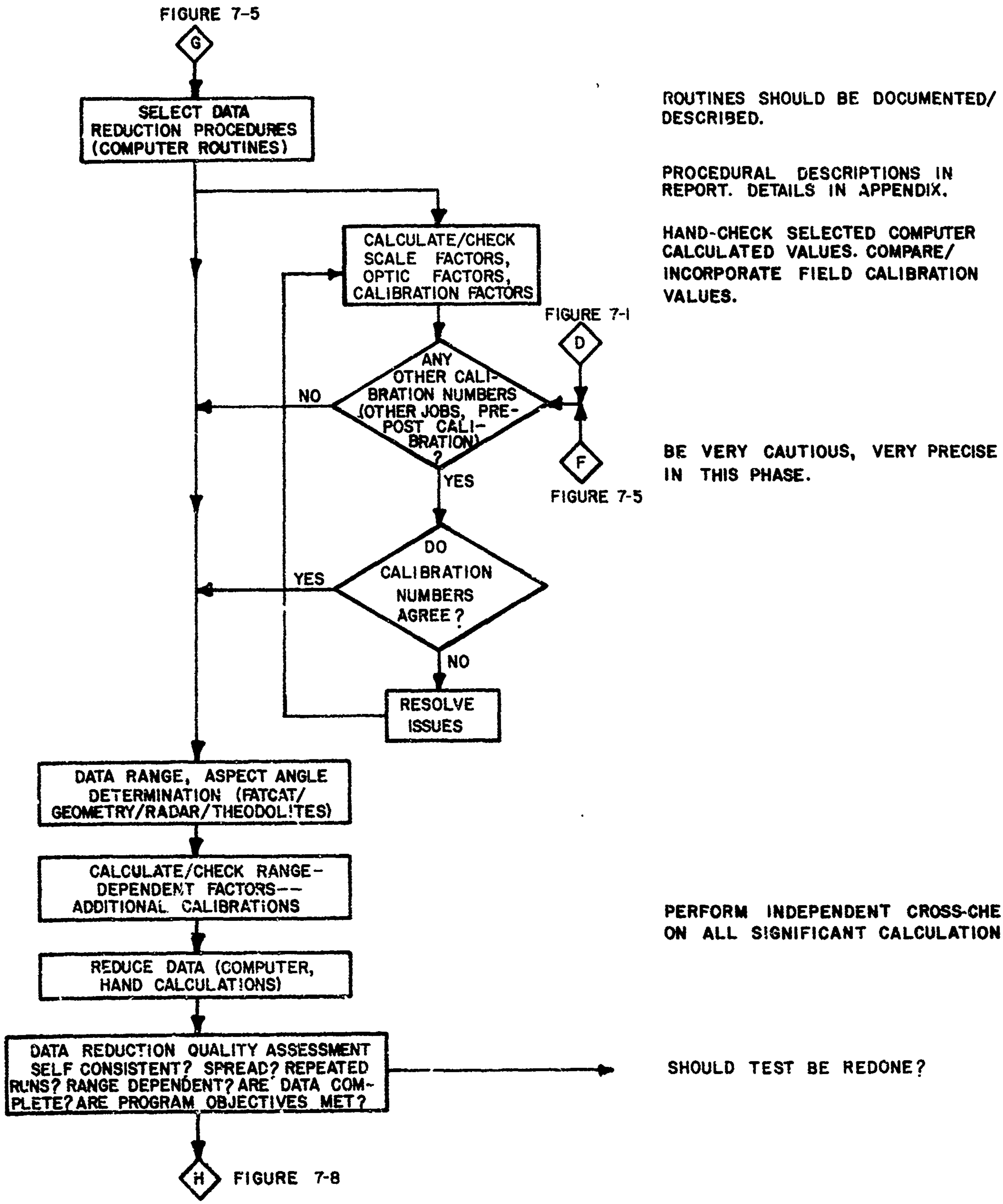


Figure 7-7. Data reduction.

At this time the laboratory calibration data, the pretest calibration data, and the post-test calibration data should be rigorously compared and analyzed. Any anomalies or ambiguities must be completely resolved prior to further data reduction activities. Often it will be of tremendous value to include calibration data from prior successful test programs in the comparison and analysis process. Particular attention should be paid to illuminating any time-dependent variations resulting from equipment aging, temperature, or other environmental effects, and even operator-proficiency effects.

It is emphasized that these steps are critical to the successful completion of the test program and that every effort should be made to be complete, cautious, and extremely precise.

Once the computational routine has been established and verified and the input functions, constants, and calibrations have been selected and verified, the initial data reduction process will often be one of obtaining the test-geometry parameters. The procedure for determining such factors as range, azimuth, and elevation angles is reasonably simple and, in most cases, rather straightforward. However, this procedure has been used without sufficient quality control in some test programs. Independent of the specific method(s) used, verification procedures can be developed to ensure the quality of the output data. Simple observation may be one such procedure; if it is known that at some specific point the aircraft was at a defined location (e.g., directly over some premeasured ground pylon), then the data obtained by the data reduction procedure should certainly agree with the physical location.

For other cases, particularly in dynamic flight conditions, observation alone is not sufficient. In dynamic flight conditions there are other physical characteristics that can be employed to advantage. Such physical characteristics might include (1) the airplane cannot fly backwards (yet there have been cases where sequential range data would indicate this); or (2) the aircraft cannot change directions instantaneously (yet some sequential aspect angle data imply it). The point here is that for dynamic flight conditions the geometrical values should represent actual flight (usually smooth) trajectories and if sequential data are sequentially plotted, insight into the quality of the data may be achieved. However, this simple method is very often not used.

With regard to trajectories, it is worthwhile to mention that by selecting the method of plotting the data, recurring geometrical points can be selected for later use. Thus, if the target is at the same point in space under the same conditions, the resultant data should have the same value and be independent of how the target got there. For example, a point from a horizontal traverse can be compared with some point from a vertical traverse if the azimuth and elevation angles agree. Note here that equal ranges are not necessary--for range differences, the only variable not already included is atmospheric absorption. For unequal range cases, the closest point has to be the larger of the two values in intensity and the actual atmospheric effect can be calculated to within the field-test level of accuracy.

Range dependency can also be checked for constant-heading fly-away runs. Since the range-squared function is inherent in the intensity calculations, the only variation in intensity that should occur is that due to atmospheric absorption--again, reasonably calculable using such atmospheric models as LOWTRAN. There certainly are many more "tricks" that can be developed and used, and such use is encouraged.

The output data obtained now enter into an assessment phase, which should ultimately address the question whether the program objectives have been met. This assessment includes items previously mentioned regarding the signature versus geometry considerations and includes the review to determine whether sufficient and complete data are available to address the project requirements.

If, when the overall data assessment is made, insufficient data have been obtained to satisfy the program objectives, it might be realistic to consider rerunning the test to acquire the additional needed data while the test resources (equipments, personnel) are still intact and operable. It is conceivable that a limited test program could be conducted to acquire the additional data necessary to satisfy the program objectives.

Data Assessment/Reporting

Although it was included previously as a separate sequence, the comparison of the newly acquired data with the expected data is also a part of the data assessment. It is included here to emphasize its essentiality. The results of this comparison effort can be instrumental in the reporting of more consistent data within the ir technical community. (See figure 7-8.)

The prior data used for the data comparison may differ in some respects from the data being reduced and compared. At this point, no assumption should be made as to which data are dominant. Whichever data are more amenable to conversion should be subsequently converted to permit the most precise correlation. As an example, if the "old" data were broadband radiometric at relatively long range, while the "new" data were short range spectroradiometric, then the most appropriate sequence would be to "range"-extend (using LOWTRAN III, for example) the spectral data; perform the necessary integration, using the spectral relative response of the radiometer; and then perform the comparison. The converted data are, of course, no longer in the output data report format; but, for correlation purposes, they will produce a much stronger, technically superior correlation assessment.

At this point we have a collection of reduced, assessed, and correlated data that can be technically supported and defended. The quality and quantity of the data, consistent with the program objectives, have been established, and the final steps of data grouping, statistical analyses, and assembly into an appropriate format for reporting can now be undertaken. Through the use of these defined, verified, and accurate data, the target characteristics may now be presented with minimal extraneous effects. The actual reporting format to be used is described in chapter 3.

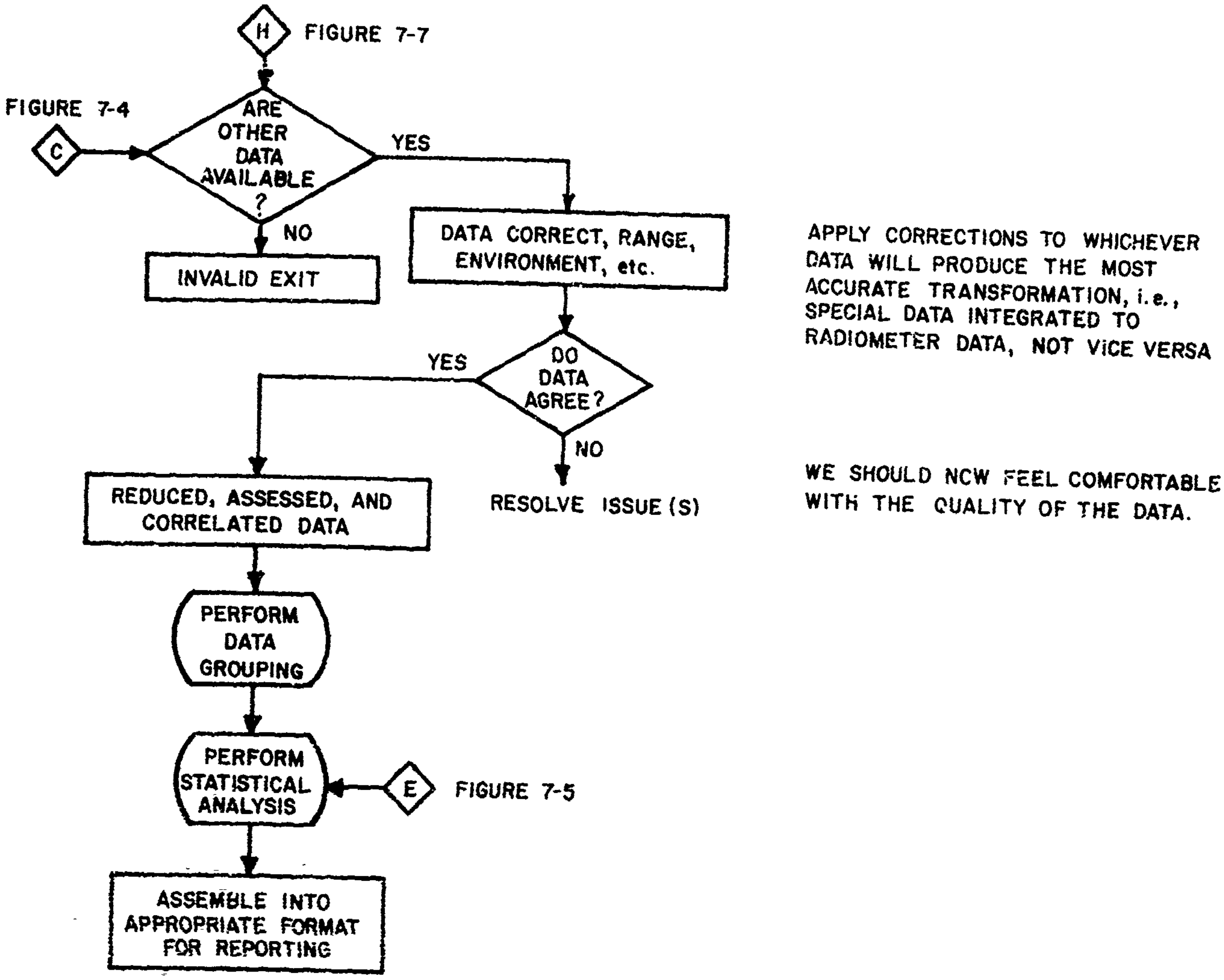


Figure 7-8. Data assessment/reporting.

SUMMARY

It has been our objective to describe a generalized methodology of measurement which may be used in some ir measurement programs. It should also be reasonably apparent that a high-quality data output is not consistently obtained by accident or luck. It will result only from a logical, well-ordered approach to the total test program.

The most important recommendation that can be made is to establish within each facility a specific, amply documented, measurement methodology. Continuous modifications can be made to the procedure to provide improved baselines by which to conduct future test programs. The end result of such an effort will benefit all elements of the ir community.

CHAPTER 8

DATA APPLICATIONS AND REQUIREMENTS

Frank Husted

INTRODUCTION

The possible applications of a measured set of data are uniquely related to the original program objectives for which the data was generated and to the formulation and conduct of the measurement program designed to achieve the specified objectives. Too many cases can be documented where a potential user, unaware of the original program requirements, has reviewed the results of a measurements program and then criticized the entire effort because his specific data application was not included. Intelligent application of measured data requires that the user have a thorough knowledge of the measurement equipment and the test procedures employed by the measurement activity to obtain the data. The user must have all the information associated with the test that will impact his requirements.

On the other hand, without a complete understanding of the intended uses of the measurements, the measurement activity can not generate a valid test plan, assess any limitations imposed by the resources available, or make recommendations concerning the type of measured data to be acquired. Consequently, the measurement activity must have a comprehensive understanding of the current and possible future applications of the data. The need for effective lines of communication between the data user and the data generator is apparent if the measurements provided are to satisfy the sponsor's requirements.

A review of the Infrared Information System (IRIS) Proceedings on Infrared Countermeasures provides a comprehensive background concerning data user and data generator categories and the myriad of applications that have mandated test/measurement evaluations. To attempt to summarize the individual features of each measurement and application requirement is beyond the scope of this chapter. A more reasonable goal entails the description of generic program characteristics that insure the consideration of the interface requirements identified in the opening paragraphs as key ingredients of a successful program.

Since the paramount objective of the evaluation effort is the satisfaction of the sponsor's requirements, the burden of responsibility shifts initially to the user in the data user/data generator interface domain. The test objective will be defined under the general heading of "Determine the Infrared Signature Characteristics of a Target Aircraft." The sponsor's specific objectives involve the acquisition of ir signature data (1) to establish the aircraft ir signature levels, (2) to assess aircraft susceptibility to lock on

by various ir-seeking missiles, and (3) to provide the necessary data to determine the passive/active countermeasures suite required to reduce aircraft susceptibility to acceptable limits. Beneath this general statement of user requirements, a plethora of details must be clarified concerning data user and data generator appreciation of (1) the types of measured data required, (2) the resources available to make the measurement, (3) target characteristics which contribute to the total aircraft signature, and (4) the effects of ambient environment and background conditions on contrast and absolute signature measurements.

The guidelines listed below provide a framework for the detailed documentation of program objectives.

- The user must provide a thorough description of the data need and include a summary of the considerations that have mandated a test and evaluation effort.

- The user must describe the anticipated uses of the data and furnish all the information associated with end item usage that will influence the conduct of the measurements.

- The user must define the critical parameters of the acquisition process.

- The user must specify the data format.

DETAIL THE DATA NEED

The sponsoring agency must clearly indicate the considerations that have mandated the test program. Such background information would stress the reasons why a specific data void exists and the type of data the sponsor needs to correct the identified deficiency. The program objectives must specify the type of measured data required. If characterization of the target signature is the primary objective, this must be clearly stated and that evaluation of a specific threat weapon or system is of secondary importance. Both parties must realize that a systems evaluation does not provide data that can be used to establish basic signature characteristics. The requirements document must specify aircraft flight envelope and engine operating conditions and the priority of air-to-air or surface-to-air ir measurements. Clarification concerning the importance of forward hemisphere or rear hemisphere aspect angle coverage is necessary since aspect angle dependence is a primary feature of the spatial and spectral characteristics of the target signature. An example of a comprehensive statement of user requirements that documents, in considerable detail, the target, background, and environment characteristics

that influence aircraft signature measurements is provided by Reed and Nicholson.[1]

DOCUMENT THE ANTICIPATED DATA USES

The user must describe the anticipated uses of the data and furnish the information associated with end item usage that will influence the conduct of the measurement program. A pitfall frequently encountered in the application of measured data is the tacit assumption on the part of the data generator and the data user that the results of the measurement program will be applied within the limitations imposed by the test conditions. Typical test conditions constraints are the limitations fixed by the measurement equipment available, the ambient environment and background characteristics, and the level of aircraft instrumentation furnished as standard aircraft equipment.

This last item deserves some additional comment since its implications are frequently overlooked by the parties involved. Normally, the standard cockpit displayed parameters such as power lever condition, engine cycle temperature, fuel flow, and rotor revolutions per minute (rpm) are presented to the pilot to provide an indication of engine cycle conditions. These readouts are not the cycle parameters that exert the decisive influence on aircraft signature levels. In the majority of cases, salient ir signature cycle parameters, such as exhaust gas temperature, exhaust nozzle skin temperature, exhaust plume temperature profiles, and engine air flow are not available. The user must be aware of the implications of the inadequate definition of engine operating conditions and resist the temptation to isolate the data from the limitations imposed by the test conditions. Once test results are isolated in this manner, there is a tendency to extrapolate measured data to points on the aircraft flight envelope where engine cycle conditions have shifted with the expectation that the signature will remain invariant.

If the data application requires the extrapolation of signature data or the prediction of aircraft signature levels at points on the aircraft envelope where measurements were not acquired, the following tasks must be accomplished:

- The ir signature characteristics of the aircraft must be determined with simultaneous recording of the cycle parameters that exert the dominant influence on ir signature.

- A computer program must be developed to model the aircraft ir signature.

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[1]Reed, F. A., and W. Nicholson, "Analysis of Infrared Suppression Requirements U.S. Army AH-1 and UH-1 Series Aircraft," Proceedings of the Fourteenth IRIS Symposium on Infrared Countermeasures, March 1977

• The computer-predicted signatures must be validated for the conditions of the ir signature measurements before the model is used to predict aircraft signature levels at other aircraft flight envelope conditions.

DOD has just completed an aircraft ir measurement program, HAVE ROBE, which was organized to accomplish the task outlined above. The results are documented in a series of reports under the auspices of the Naval Weapons Center.[2] The principal objective of the HAVE ROBE project was to establish the ground static and the inflight ir signature characteristics of the aircraft correlated with actual engine operating conditions. The ir measurements were made to determine the aircraft ir signature in spectral bands of current interest for operational and advanced development systems.

Prior to making any aircraft ir measurements or specifying aircraft instrumentation requirements, a sensitivity analysis was undertaken to determine the engine parameters that exert a decisive influence on aircraft signature levels. The engine sensitivity analysis was accomplished using the General Electric SCORPIO III computer prediction program.[3]

The results of the sensitivity analysis[4] are presented in terms of influence coefficients that relate the percent change in aircraft signature level to a percent change in the engine cycle parameter of interest; for example, exhaust gas temperature. In this way, aircraft and propulsion system instrumentation requirements were established and the necessary engine cycle data was provided to model the aircraft ir signature. The ir signature model was then validated for the conditions of the ir measurements before the prediction program was used to generate signatures for other aircraft flight envelope conditions.

DEFINE THE CRITICAL PARAMETERS

The user must define the critical parameters of the data acquisition process such as the type of measured data required, the aircraft flight envelope and corresponding engine operating conditions, and the ambient environment and background conditions. A fundamental requisite is the adequacy of the instrumentation and measurement equipment on hand to obtain the data. Too many times, the instrumentation available and not the sponsor's need dictates the type of measurements provided. Ambient temperature and background effects play a major role in the acquisition of ir signature data from suppressed

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[2]Kummer, D., "Have Robe Basic Infrared Measurements Test Plan," Naval Weapons Center Technical Memorandum 2558, September 1975

[3]Wilton, M.E., "Turbine Engine IRS Program," General Electric Company R73AEG320 under Contract No. F33615-72-C-2185, September 1973

[4]Wilton, M. E., and G. E. Varney, "Engine Sensitivity Study," General Electric Company Technical Memorandum TM Number 76-667, December 1976

targets where minimal contrast is available between the target and the background. Diffuse and specular sun glint from canopy and fuselage surfaces are unique functions of the location, geometry, atmospheric, and day conditions at the time of the measurements. The role of atmospheric absorption and the necessity of documenting the atmospheric parameters that contribute to radiation absorption cannot be over emphasized. Table 8-1 is furnished to assist the user in identifying the controlling factors of a measurement program that exert a decisive influence on measurement results.

SPECIFY THE DATA FORMAT

A data format compatible with the sponsor's requirements must be specified. The data format must present the type of data required and facilitate the data analysis. All the pertinent information required to characterize the conditions of target, background, and environment must be specified. Chapters of this guide specifically addressing this area should be reviewed to gain detailed insight into matters only highlighted here.

TABLE 8-1. CRITICAL DATA ACQUISITION FACTORS

	Target Description			Flight Conditions	
Detailed Description Action	Aircraft Type	Engine Type	Detailed Description	Flight Profile	Aircraft Configuration
Resolution	Fighter[a]	Turbojet[b]	Single engine	Altitude	Gross weight
Spectral			Twin engine	Mach number	External stores
Spatial	Attack[c]	Turbofan[d]	Suppressed	Heading	Speed brakes deployed
Temporal			Unsuppressed	Range traverse	
Sensitivity	Helicopter[e]	Turboshaft[f]	Engine cycle description		
Field of View					
Contrast measurements			Cockpit recorded parameters		
Resolute measurements					

Background	Supporting Range/Acquisition Instrumentation	Data Reduction Procedures/Format
Blue sky	Tracking systems	See chapters 4 and 7.
Token clouds	Monitoring systems	
Desert terrain	Data acquisition systems	
Solar conditions		

For example: [a]F-4J; [b]J79-GE-17; [c]A-7E; [d]TF41-A-2; [e]CH-53E; [f]T64-GE-415

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